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FINAL REPORT

RU # 108 - PHASE I

August 1975 - October 1977

COMMUNITY STRUCTURE, DISTRIBUTION, AND INTERRELATIONSHIPS OF MARINE BIRDS IN THE GULF OF ALASKA

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SUMMARIZATION

Census Methods

To study the population and community dynamics and energetics of marine birds, and to assess oil development impacts on bird populations, accurate density estimates of birds at sea are essential. The line transect is the most suitable method for this purpose. We describe a standardized method for transect censusing of marine birds from shipboard at sea. All birds seen in an arc of 90°, from the bow to one beam, are recorded over 15-30 min transect runs. For each sighting, the number of birds, species, distance, the angle from the transect line to the birds, and the direction of flight of flying birds are recorded. Distances are determined using a rangefinder developed specifically for this task. Using these data, densities are calculated from information on the frequency of sightings in distance intervals perpendicular to the transect line. Representative "detection curves" for major marine bird species are presented. Problems in the collection of such transect data arise when the density of birds in an area is very high, when weather or sea conditions are unsuitable for use of the rangefinder to determine distances, or when birds are attracted to the observer's ship. Partial solutions to these sampling problems are suggested.

Six conditions tend to decrease the accuracy and/or precision of density estimates of marine birds. They are 1) patchy distributions of the birds, 2) non-uniform detection probabilities during a transect or among different members of the population, 3) the detection of one bird leading to the detection of other birds, 4) measurement errors, 5) less than complete detection on the transect line, and 6) movement by the birds. The first four tend to decrease the precision and occasionally the accuracy of transect census estimates, but we conclude that these errors can usually be maintained at acceptable levels by the appropriate survey design and sampling method. The effect of the last two conditions is to decrease the accuracy of census estimates, often drastically. Incomplete detection on the transect line will lead to underestimation and may be very common at sea for most species. We speculate on how one might determine the magnitude of this bias, but the problem has yet to be examined closely. The effect of bird movement is investigated by computer simulations of pelagic transect conditions. These show that the effect of bird movement is to severely decrease the accuracy of census estimates in some cases. Both the velocity and angle of flight of the birds relative to the observer are important. However, there is a highly significant relationship between the estimated density and true density and relative velocity. Applying a correction factor derived from this regression effectively removes any biases due to bird movements relative to the observer for all but one of the estimators we simulated. Based on these findings and an analysis of line transect theory as applied to pelagic bird censusing, we suggest a generalized field and analytical method for the estimation of bird densities at sea.

Transect Census Results

Densities of marine birds determined by transect censusing are considered by 13 time-area blocks, largely contained in the Gulf of Alaska. Overall seabird densities in the Northeast Gulf of Alaska (NEGOA) doubled from April to May, reflecting an influx of migrant populations. The Kodiak region had low spring densities but high densities in late summer and fall, largely due to the presence of vast concentrations of shearwaters. Patterns for the major species were as follows. Fulmars were found throughout the areas covered in all months sampled, but in greater abundance in the western Gulf and the Bering Sea than in the NEGOA. Shearwaters (perdominately Short-tailed and Sooty) exhibited complex distributional patterns, but were present in most areas at most times, often in extremely high densities. Fork-tailed Storm-Petrels were not found in the NEGOA in April, but returned to occupy primarily areas from the continental shelf break outward in May. Jaegers likewise returned to NEGOA in early May, and were widely distributed from June through August. Large gulls (Glaucous-winged, Herring, Thayer's, and Glaucous) occurred frequently in the area, being especially widespread during the non-breeding season. In summer only Glaucous-winged gulls remained at sea in any numbers, but they were concentrated near shore. During summer most gulls occur near shore. Black-legged Kittiwakes were recorded in all areas in all months sampled. Densities were greatest in the Kodiak area, and summer abundances were typically greater than in the non-breeding season. Arctic Terns migrated north into the NEGOA in late April and early May, departing in late August-September. During their breeding season in June they were not seen at sea. Common Murres were present in all areas at all month sampled; Thick-billed Murres, on the other hand, were not found east of Kodiak, and were more frequently encountered in the NWGOA and Bering Sea, where Common Murres were less abundant. Horned Puffins were rarely recorded in the NEGOA and Kodiak areas until late May, and low densities were recorded by transects during summer (when the birds were concentrated close to their breeding colonies). Highest densities were recorded in the Kodiak area in October, when the birds were apparently dispersing to their wintering areas in the North Pacific. Tufted Puffins were present in the study areas in all months sampled. Densities were greatest in nearshore waters in summer and off the continental shelf in spring and fall, and increased greatly from east to west.

Assessment of these patterns in relation to environmental variables revealed that the temperature-salinity gradient found over the continental shelf and slope was associated with the distributions of several species. Sooty Shearwaters and Tufted Puffins may avoid the offshelf waters in response to temperature, while Short-tailed Shearwaters and Fulmars may avoid the shelf in response to salinity.

Feeding Flocks

Marine birds frequently form feeding assemblages containing several species, presumably in response to local concentrations of prey (schooling fish, etc.). In studies of such flocks in the Gulf of Alaska, we gathered information on flock composition, duration, and the behavioral actions and reactions of the flock participants. Three categories of flocks can be distinguished. Type I flocks are usually small (less than 500, often less than 50 individuals) aggregations that are short-lived and occur nearshore, within 5 km of shore; gulls, kittiwakes, puffins, and cormorants predominate in these flocks. Type II flocks are much larger and longer-lived, forming over food concentrations that presumably remain available to the birds longer; in Alaska, alcids tend to avoid such flocks. These flocks have a variable distribution (probably depending on the nature of the food source), occurring from 1 km out to the continental shelf margin, but typically fairly close to shore. Type III flocks occur when local water mass discontinuities, such as rip tides, concentrate prey; most nearshore marine bird species may be involved in such flocks.

Eighteen species were recorded participating in mixed-species feeding flocks in Alaskan waters. Gulls accounted for 38% of the flock participants (predominately Black-legged Kittiwakes and Glaucous-winged Gulls), shearwaters for 25%. Flock participants fall into one or more functional groups determined by the role they play in flock organization. Catalysts are birds whose foraging and feeding behaviors are highly conspicuous, and which therefore promote rapid flock formation as other species respond to these behaviors as cues of food location. Black-legged Kittiwakes were the major catalyst species in the areas we studied. Divers such as alcids or cormorants feed by diving or plunging for prey. Kleptoparasites pirate food from other birds. In the flocks we studied, jaegers associated with flocks only in this manner, while kittiwakes and gulls opportunistically attempted to rob other flock members, in addition to their usual foraging modes. Suppressors are species whose feeding sharply decreases the availability of prey to the other flock members, presumably by dispersing or decimating the prey concentration. Shearwaters may frequently have this effect on feeding flocks.

Typically Type I feeding flocks are initiated when one or more catalyst individuals locate a prey concentration, and the features of their feeding behavior attract other individuals and species to the location. Cormorants typically fly to the center of a flock, alight, and then dive. Alcids pursuit-plunge into the water at the boundaries of the flock and swim in underwater. Shearwaters fly to the center of the flock and pursuit-plunge. Such a pattern of flock build-up continues until contact with the prey concentration is presumably lost, at which time the flock begins to decay and disperse.

The patterns of flock organization bear some likeness to a cooperative unit, with clear species interdependencies. The catalyst species, in finding and initiating feeding on a prey concentration, act to alert other species to its presence and attract them to feed. Some of these species, such as cormorants and (especially) shearwaters, may act in a disruptive manner, their vigorous pursuit-plunging and diving leading to a dispersal of the prey concentration. Other divers, such as puffins and other small alcids, remain largely at the periphery of the feeding flock, perhaps to avoid kleptoparasitic attacks from kittiwakes and gulls. In so doing, their activities may act to prevent lateral spread or sounding of the prey concentration, and thus contribute to a greater duration of feeding activities by the flock as a whole. Despite such appearances of cooperation for mutual benefit, the most parsimonious interpretation of flock organization and activity is one based upon individual selfishness.

Potential Impacts of Petroleum Development

Birds may play important roles in marine ecosystems in energy flow and nutrient cycling. As many species are sensitive to both direct and indirect effects of oil pollution, these roles may be threatened by large- or even small-scale pollution events. Distributionally, areas in the Bering Sea and Aleutian passes appear to be more fragile than areas in Lower Cook Inlet and the NEGOA, due to their larger populations of birds and important breeding colony locations. While large-scale pollution events in these marine systems may have major effects on bird populations, small localized "incidental" pollution events should not be ignored. If these occur in the immediate vicinity of breeding colonies, or destroy local food concentrations, their effects may be severe. Other "minor" pollution events that affect species playing key roles in mixed-species feeding flocks, such as kittiwakes or puffins, may have secondary effects on other species participating in or reliant upon these feeding aggregations. Obviously, the variety of possible avenues of primary and secondary effects of marine pollution on bird populations and communities precludes simple predictions.

INTRODUCTION

The objectives of this research, as outlined in the original work statement and later ammended, concentrated on documenting various aspects of the distribution, abundance, and interactions of marine birds in the Gulf of Alaska. More specifically, we sought to:

1) Determine the distributional occurrence and abundances of marine bird populations in various areas of the Gulf of Alaska, at various times during the year, from shipboard censuses;

2) Describe the composition and organization of mixed species feeding flocks, paying special attention to the patterns of species interdependencies and the form of flock organization;

3) Assess the adequacy of several transect census methods by computer simulation---the results of this analysis should provide guidelines for future marine bird transect censusing, and for adjustment of censuses conducted to date, if necessary; and

4) Evaluate the trophic impacts of marine birds in coastal ecosystems, through analysis of their food habits combined with computer simulations of energy flow through populations.

Of these objectives, our emphasis initially was upon gathering information in the field on items 1 and 2. The analysis of this information has proven to be laborious and time-consuming, but is now virtually complete, with manuscripts in varying stages of preparation for publication. Efforts on item 3 were initiated later in the program (when additional funding became available and our field studies were nearly completed), but the basic computer simulations have been completed and their results can be evaluated. Our efforts to obtain information on food habits of marine birds proved largely unsuccessful, due both to time constraints resulting from higher priority tasks while in the field, and to the difficulty of collecting feeding marine birds at sea. A total of 51 specimens of 14 species was collected during our field studies, and these now await dietary analysis by U.S. Fish and Wildlife Service personnel. Analyses of energy flow dynamics have been delayed with the initiation of continued funding of RU # 108 to conduct broader computer simulations; these analyses are best conducted together.

In this report we consider various methods of transect-based density estimation, detail the major findings of our studies of marine bird distribution and abundance in the Gulf of Alaska, and describe the patterns of organization typifying mixed species feeding flocks in this region. A final section evaluates our views regarding the influences of petroleum development on the populations and population attributes we studied. This report includes and adds to information presented in earlier progress reports.

A TRANSECT CENSUS METHOD FOR MEASURING DENSITIES OF SEABIRDS

Accurate determination of seabird densities at sea is necessary for the assessment of the role of birds in Marine Ecosystems. Past studies (Sanger 1972, Wiens and Scott 1975) indicate that this role in nutrient and energy cycling may at times be quite large. Area-specific and season-specific seabird density information is also necessary for predicting the consequences of increased utilization of the oceans for oil transport and production, and of increased oceanic fish harvests.

Previous shipboard censusing techniques have generally been aimed at obtaining repeatable relative density or abundance estimates. King (1970) summarized the Pacific Ocean Biological Survey Program (POBSP) method, which entailed continuous recording in a 270° arc and calculation of birds seen per linear mile and birds seen per hour. Sanger (1970) estimated relative densities from counts of birds seen around a stopped ship. Brown et al. (1975) used a method similar to the POBSP method, but counted in 10 minute watches to derive estimates of birds per hour.

FIELD METHODS

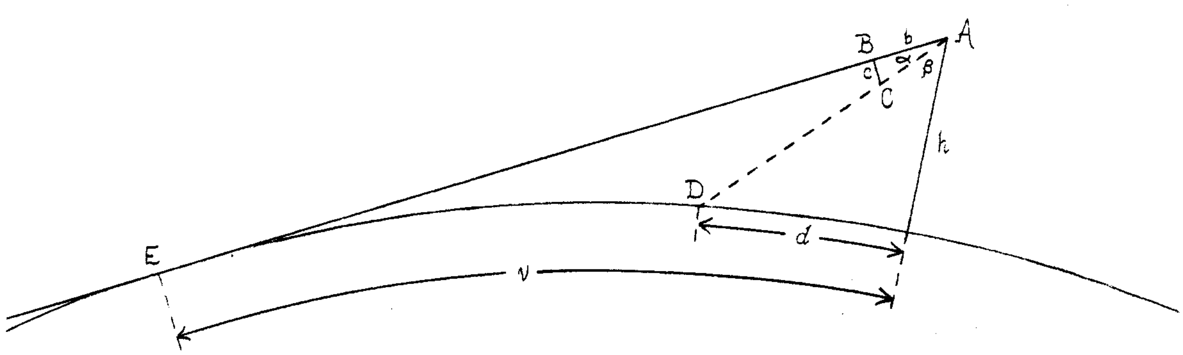
Data Collection

The observer selects a standard position, preferably 7-12m above the waterline of the ship, with an unobstructed view forward and to the side. Similar positions should be available at the same height and distance from the bow on both sides of the ship. All birds seen in an arc of 90°, from the bow to one beam, are recorded. The observer normally choses the side with the best light and wind conditions. We use 15 and 30 minute periods for our standard transect lengths, but the method will allow use of any transect length. The ship must be on a constant heading, and at a constant speed for the period of the transect. At frequent intervals through the transect, the time is recorded, so that within-transect distribution of bird density can be assessed if necessary. When birds are at low density the time may be recorded for each sighting (as was done by POBSP). For each transect, beginning and ending geographical positions must be recorded, to the greatest precision available. Depending on the navigational equipment in use, the best position data may be interpolated positions between infrequent but accurate positions. Extensive weather and sea condition data are collected to use in calculation of observability correction factors. They may also be useful for correlation to bird behavior and distribution. Glare conditions have a particularly important effect on observability and detectability. Sun reflection on the water severely limits visibility of birds, so when possible, the side of the ship used should be chosen to minimize sunglare.

We record the information collected on each sighting vocally with a compact cassette tape recorder. Immediately after completion of a transect we transcribe the tape onto intermediate data forms. These provide a readable hard copy of the data and are useful for hand analyses. The data are then coded and entered in the standard (NODC/OCSEAP) seabird transect format on keypunching forms. For each sighting of a bird or group of birds we attempt to identify to species, and when possible to age class and color phase.

The number of birds, the distance to the birds when first seen, the angle from the transect line to the birds at first sighting, and the direction of flight for flying birds are also recorded. When numbers of birds in large groups are obtained by means other than direct counts, the counting method used is recorded (counted by fives, tens, 50s, 100s, etc.). Distance to the birds is obtained by using a horizon-based rangefinder developed specifically for this task. Distances are notably difficult to estimate at sea and an objective measuring system is essential.

The rangefinder is basically a caliper with one fixed jaw and one moveable jaw. The caliper is held at arm's length and the upper jaw is aligned with the horizon. The lower jaw is then aligned with the object sighted while maintaining the alignment of the upper jaw with the horizon. The caliper reading then gives a measure of the object's angle below the horizon. The caliper reading can be converted, using trigonometry, to the distance from the observer to the object. The formula for conversion is derived from the following graphical representation:



Point 'A' represents the observer eye, point 'B' the upper jaw of the caliper, point 'V' the visual horizon, point 'C' the lower jaw of the caliper, 'D' the sighted object, 'b' is the distance from the observer's eye to the rangefinder, 'c' is the caliper reading, 'h' is the observer's eye height above sea level, 'd' is the distance to the object sighted, and 'v' is the distance to the visual horizon. Given 'b', 'c', 'h' and 'v', 'd' can be calculated fromthe following relationships:

$d = h \tan \beta$ where $\beta = \arctan (v/h) - \alpha$ and $\alpha = \arctan (c/b)$

which gives $d = h \tan [\arctan (v/h) - \arctan (c/b)]$

under average atmospheric conditions $v = [1.317 \sqrt{h(ft)}]$ miles

Another form of the rangefinder uses several fixed jaws, the uppermost again being aligned with the horizon. The other 'jaws' are fixed at predetermined distances below the upper 'jaw'. The 'jaws' are actually pointers which can be fastened along a long flat piece of plexiglas, wood or metal with a ruler attached to it. The pointers define the boundaries of zones below the horizon. The zones (expressed as set 'd' values) desired are determined and then, given 'h', 'v', and b, the corresponding 'c' values for positioning the pointers can be obtained from the following equation:

$$c = b \tan [\arctan (v/h) - \arctan (d/h)].$$

Since use of the rangefinder must be limited to suitable weather conditions (see below under problem situations), and since rangefinder use may be critically time consuming when birds are abundant, the observer can most profitably use the rangefinder for self-training in distance estimation and frequent recalibration. By first estimating without the rangefinder and then checking distances with it, most observers will quickly learn to accurately estimate distances.

We estimate direction to the birds when first seen in 15 degree increments and record them as clock directions. Directly ahead on the ship's course is 12, 90° to port is 3 o'clock, 90° to starboard is 9 o'clock, and so on. We record the direction of flight of flying birds also as a clock direction relative to the course of the ship.

Calculation of Densities

Sightings of individuals or flocks of a given species are grouped into zones by their perpendicular distance from the transect line. Typically the number of sightings will decrease in somc fashion with distance from the transect line. This decrease is largely a function of the size, color, and behavior of the bird, and of the optical limitations of the observer's eyes. We make the assumption that the transects are placed randomly with respect to the distribution of the birds. A typical histogram of sighting frequency by distance, along with its smoothed form or "detection curve" is shown in figure 1.

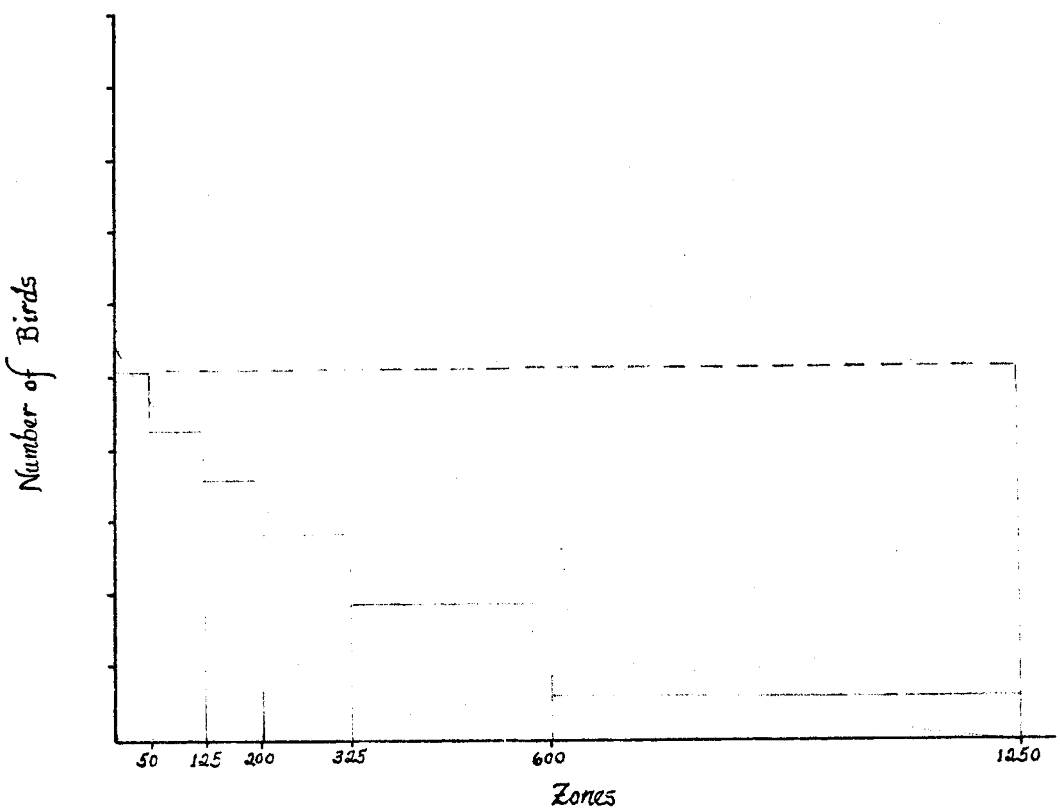
We assume that all individuals in one or more of the inner zones are detected. The frequency of occurence in those zones is extrapolated out to the transect boundary on the assumption that density is uniform over the area sampled (dashed line, figure 1). The following relationship gives the number of individuals expected (E(N)) over the area sampled: E(N) = A/A' N', where A is total area; A' is the area of the inner zones used to define the extrapolation level, and N' is the number of individuals detected in A'.

For a given bird type all sightings are pooled by time-area blocks (Table 5). Detection histograms are constructed for each block, and E(N) determined. For each block the ratio of N, the total number detected, to E(N) gives the average proportion of the "population" detected, or coefficient of detectability (C.D.). Transect-specific densities are given by ratio of the total number of sightings for that transect (n) divided by the C.D. (note: n/C.D. = E(n)) to the area sampled. The area sampled is given by the width of the transect times the distance traveled. The latter is determined by standard navigational techniques (e.g., visual, satellite, radar, or loran fixes). The width is defined by the outer boundary of the last zone, which is chosen so as to include virtually all identifiable sightings.

Choosing Zones

During a transect, distances to birds sighted are recorded by zones, or as point estimates when using the caliper type rangefinder. For our analysis the latter were lumped into our six field zones: 0-100, 100-200, 200-300, 300-500, 500-800, and 800-1250 meters. The outer boundary (1250m) represents

Fig. 1



Hypothetical distributions of sightings with distance from the transect, with an associated "detection curve" (dashed line).

our "identification horizon". For some species a wider transect is needed to determine completely the detection function, but we are constricted by our optical limitations. The first three zones were chosen to be compatable with the U.S. Fish and Wildlife's sampling methods. The outer zones exponentially increase in width, with distance from the observer, to compensate for a concurrent increase in percent error of the associated distance estimates. Perpendicular distances used in the determination of the C.D.'s are obtained by, $d_{perpendicular} = d_{radial}$ sin (sighting angle), where d_{radial} is the midpoint of a zone and the sighting angle is expressed in degrees (0-90 in 15° increments). The perpendicualr distances are condensed into six zones each containing an equal number of 36 non-zero distances (0-50, 50-125, 125-200, 200-325, 325-600, and 600-1250 m).[1]

Detection Curves (Figures 2-18)

Typically there are greater within-species differences in detection curves between birds flying and birds sitting on the water than between species. The shape of the detection curve is a function of several factors, the most important of which effect the width of the basal peak (mode) used in extrapolating to E(N). The mode of the detection function will vary (i.e., move left or right) in the specified manner with the following variables:

1) inversely with wave height, glare, or precipitation
2) directly with visability
3) directly with contrast of the bird against its background
4) it will be larger for flying birds than sitting birds
5) it will be larger for sitting birds that flush than for those that dive

---

1. The six radial zones and seven sighting angles give forty-two combinations, six of which are zero, and are all included in zone 1.

6) directly with observer's height above water [to a limit (60-80 ft), above which it varies inversely]

7) directly with the species' tendency to avoid ships and directly its tendency to be attracted

The curve in figure 1 is typical for birds on the water or very small birds; see detection histograms for Fork-tailed Petrel (figure 6), jaeger species (figure 8), Black-legged Kittiwake on the water (figure 12), or Tufted Puffin on the water (figure 18). C.D.'s for this type of curve typically range from 0.1 to 0.2 (i.e., 10-20% of the "population" detected). In all of the above cases just the first zone was used to determine E(N). In other cases the decline is not so orderly or steep as complete detection is occurring over more than the first zone (e.g., figure 17). By far the most common form shows the effect of ship avoidence, where the curve appears to be a truncated normal distribution (i.e., figures 4, 5, 13,15. The latter phenomenon is exhibited by flying birds and somewhat by birds that readily flush from the water. The same type of curve is obtained for highly visible species that are detected long before we have a chance to get close. Avoidance is probably responsible for modal peaks in zone three (125-200m) for murres, Sooty Shearwaters (figures 13 and 4) and in zone five for Short-tailed Shearwaters. Conspicuousness is exhibited by all flying gulls, Arctic Tern, Horned Puffin, and for large gulls on the water. The predominence of white on these birds is largely responsible for their conspicuousness (e.g., compare flying Horned and Tufted Puffin figures 15 and 17).

C.D.'s are easy to determine for the above patterns. However, in some species the position of the zone of complete detection is not obvious. A combination of two color phases and attraction to ships makes the curve for the Northern Fulmar difficult to interpret (figure 2).

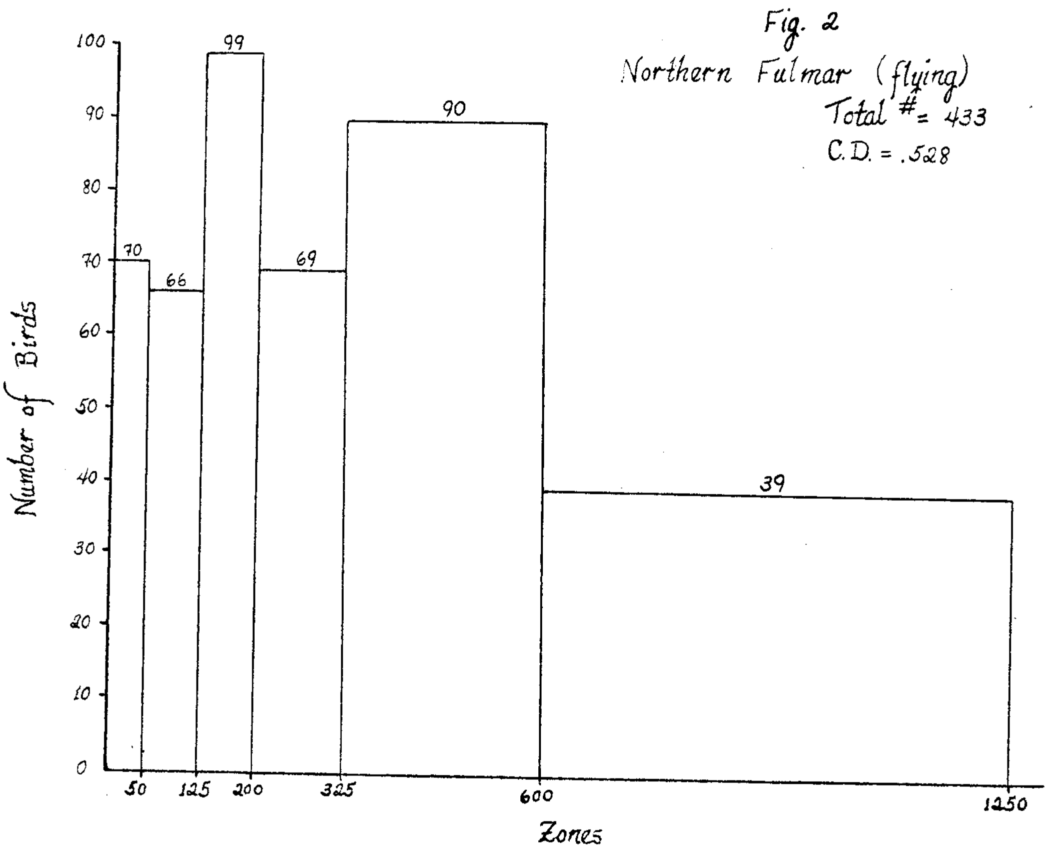


Fig. 2
Northern Fulmar (flying)
Total # = 433
C.D. = .528
Number of Birds
Zones
0
10
20
30
40
50
60
70
80
90
100
50
125
200
325
600
1250
70
66
99
69
90
39

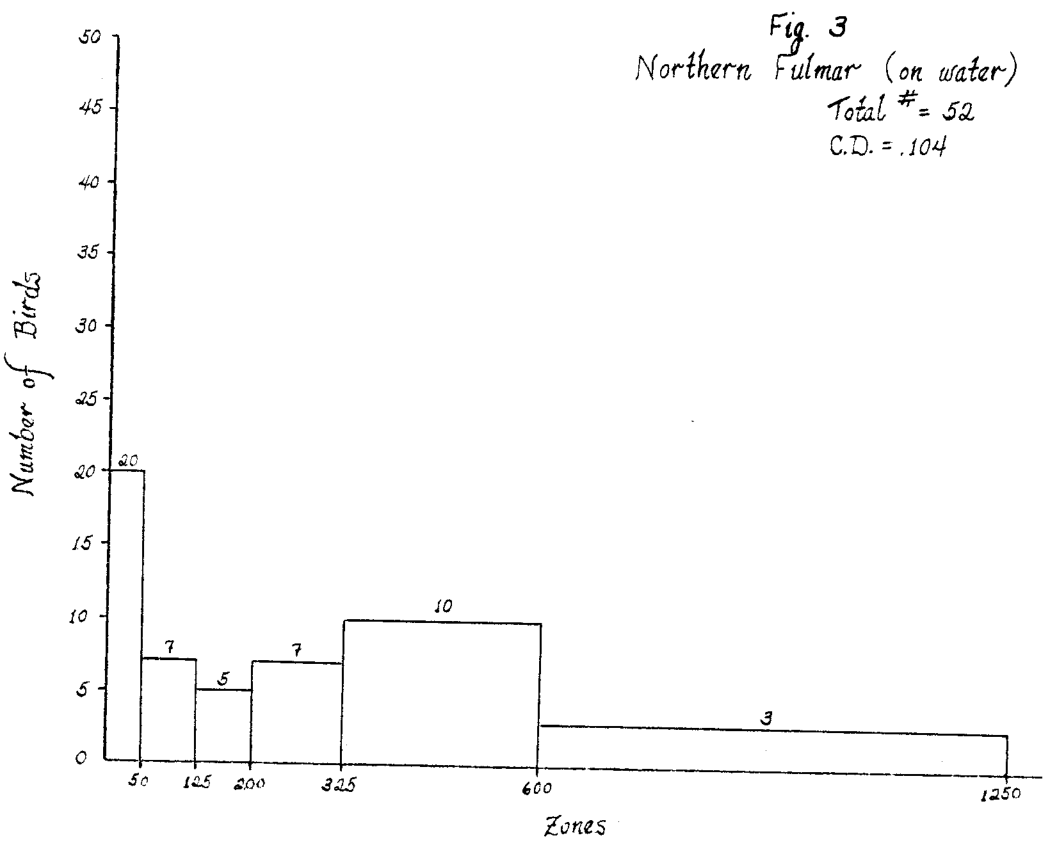


Fig. 3
Northern Fulmar (on water)
Total # = 52
C.D. = .104
Number of Birds
Zones
0
5
10
15
20
25
30
35
40
45
50
50
125
200
325
600
1250
20
7
5
7
10
3

Fig. 4

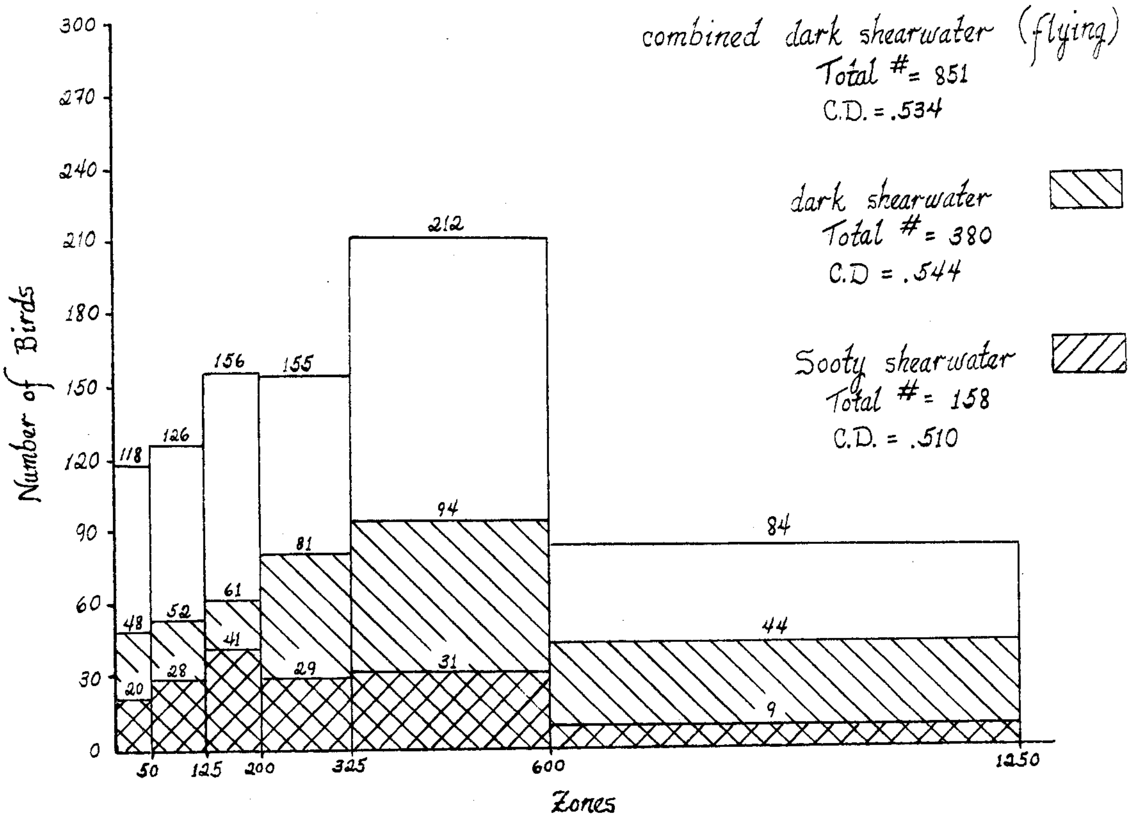
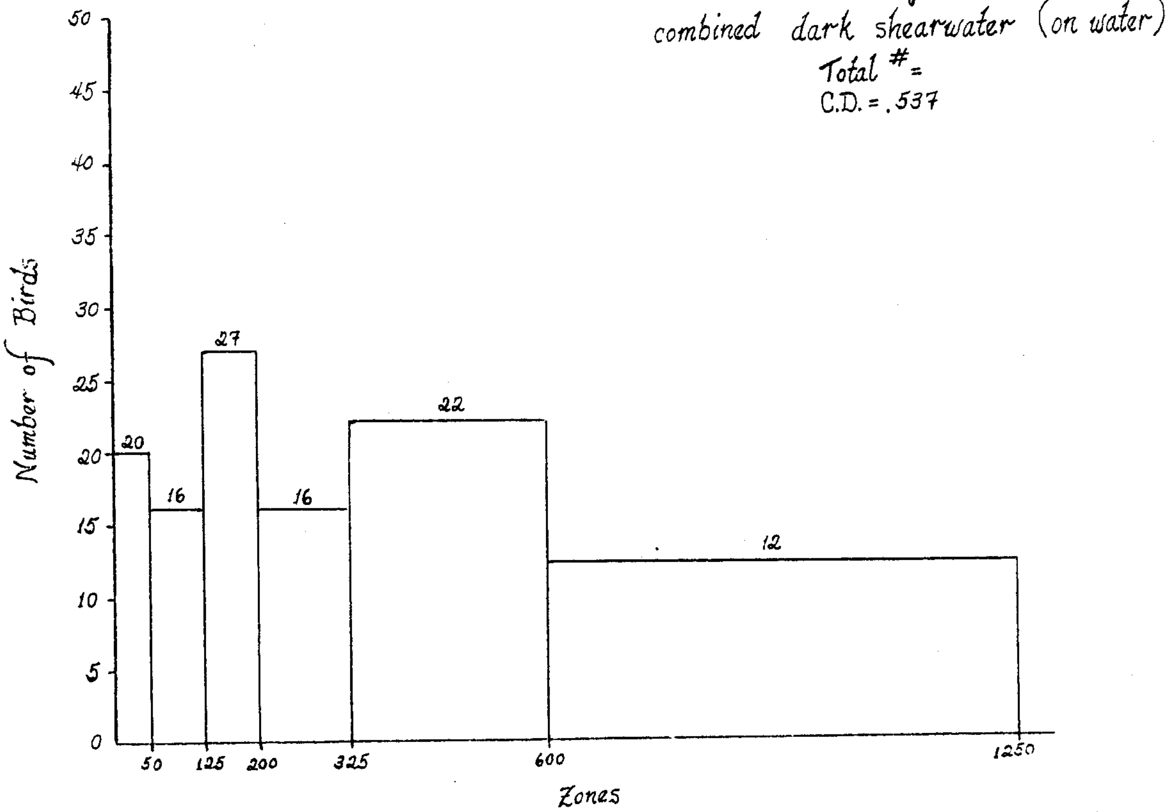

combined dark shearwater (flying)
Total # = 851
C.D. = .534
dark shearwater
Total # = 380
C.D = .544
Sooty shearwater
Total # = 158
C.D. = .510
Number of Birds
Zones
300
270
240
210
180
150
120
90
60
30
0
50
125
200
325
600
1250
118
126
156
155
212
48
52
61
81
94
84
44
20
28
41
29
31
9

Fig. 5


combined dark shearwater (on water)
Total # =
C.D. = .537
Number of Birds
Zones
50
45
40
35
30
25
20
15
10
5
0
50
125
200
325
600
1250
20
16
27
16
22
12

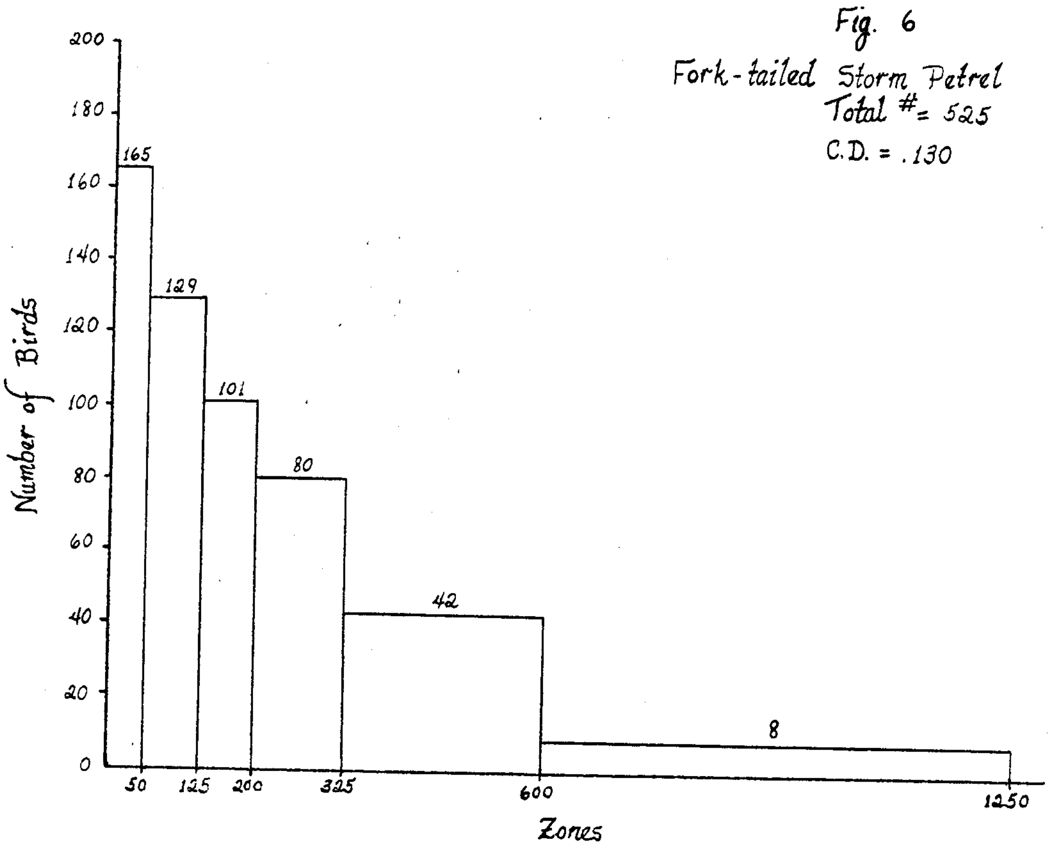


Fig. 6
Fork-tailed Storm Petrel
Total # = 525
C.D. = .130
Number of Birds
Zones
200
180
160
140
120
100
80
60
40
20
0
165
129
101
80
42
8
50
125
200
325
600
1250

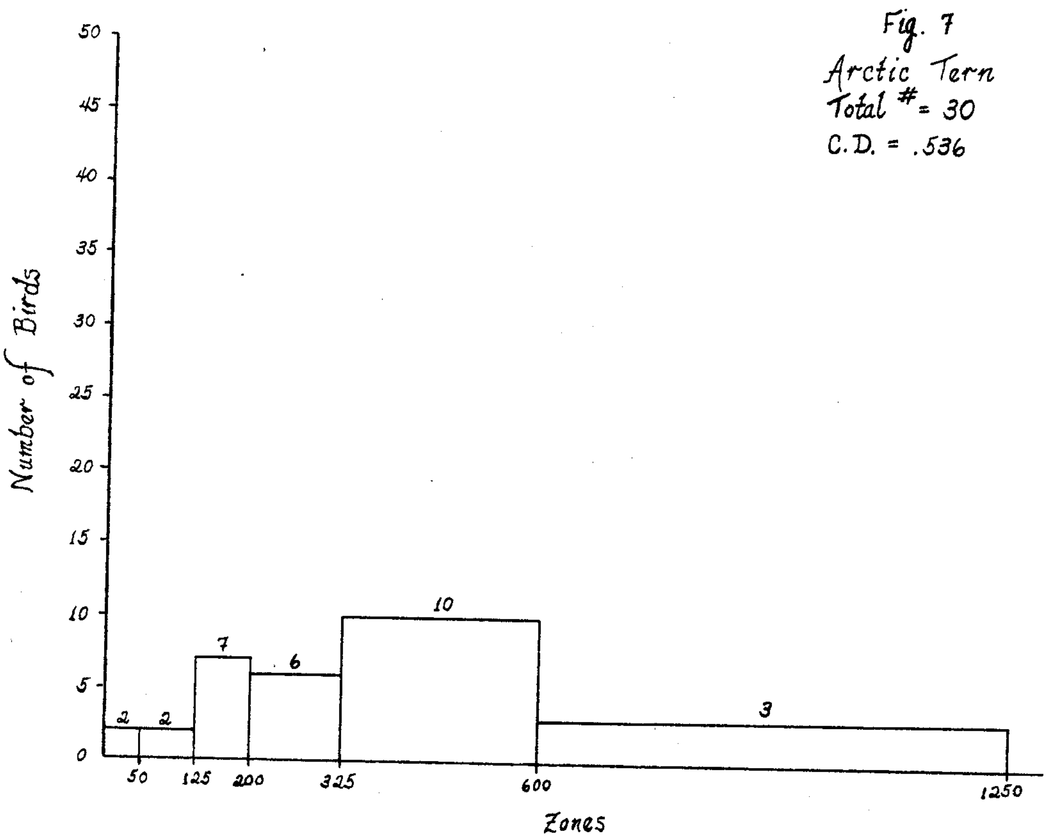
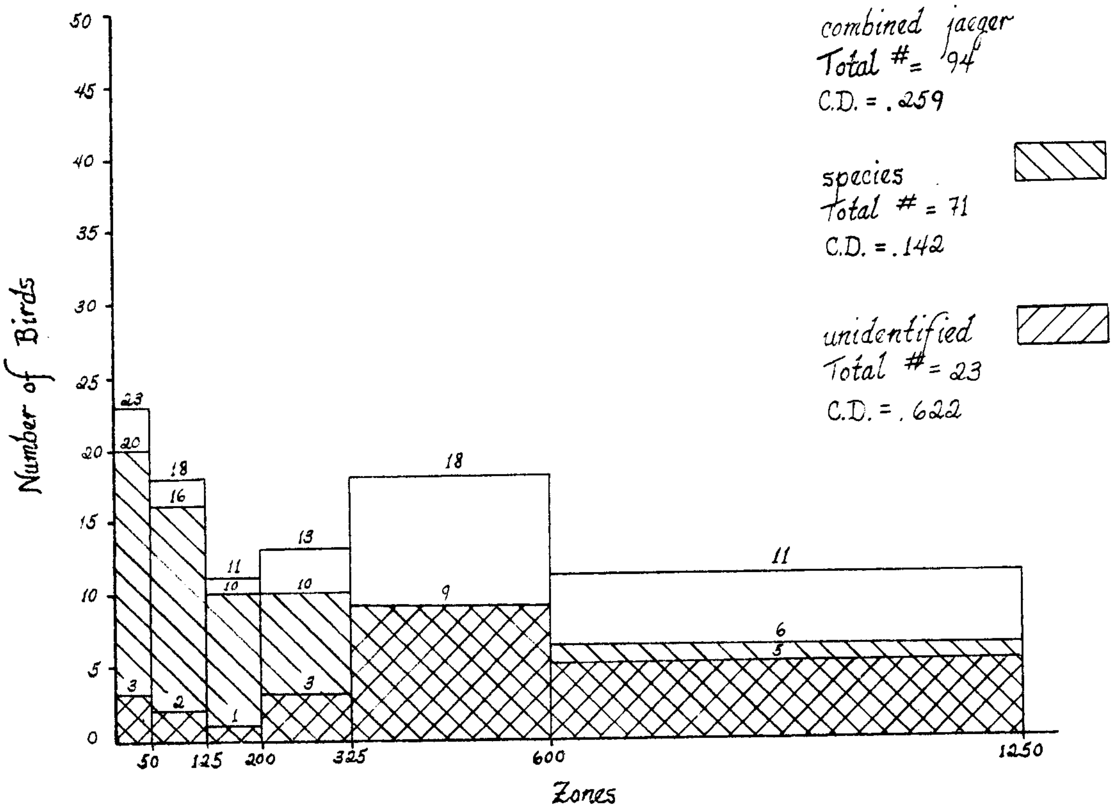


Fig. 7
Arctic Tern
Total # = 30
C.D. = .536
Number of Birds
Zones
50
45
40
35
30
25
20
15
10
5
0
2
2
7
6
10
3
50
125
200
325
600
1250

Fig. 8



combined jaeger
Total # = 94
C.D. = .259
species
Total # = 71
C.D. = .142
unidentified
Total # = 23
C.D. = .622
Number of Birds
Zones
0
5
10
15
20
25
30
35
40
45
50
50
125
200
325
600
1250
23
20
3
18
16
2
11
10
1
13
10
3
18
9
11
6
5

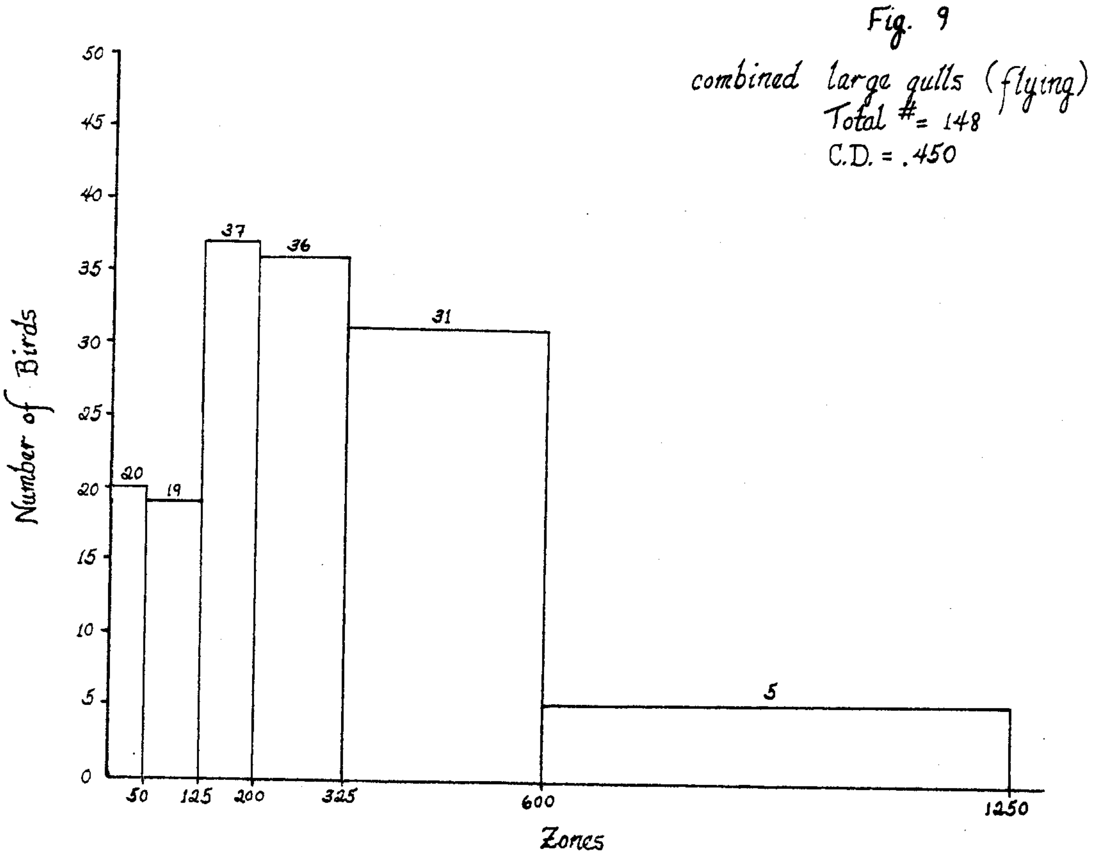


Fig. 9
combined large gulls (flying)
Total # = 148
C.D. = .450
Number of Birds
50
45
40
35
30
25
20
15
10
5
0
20
19
37
36
31
5
50
125
200
325
600
1250
Zones

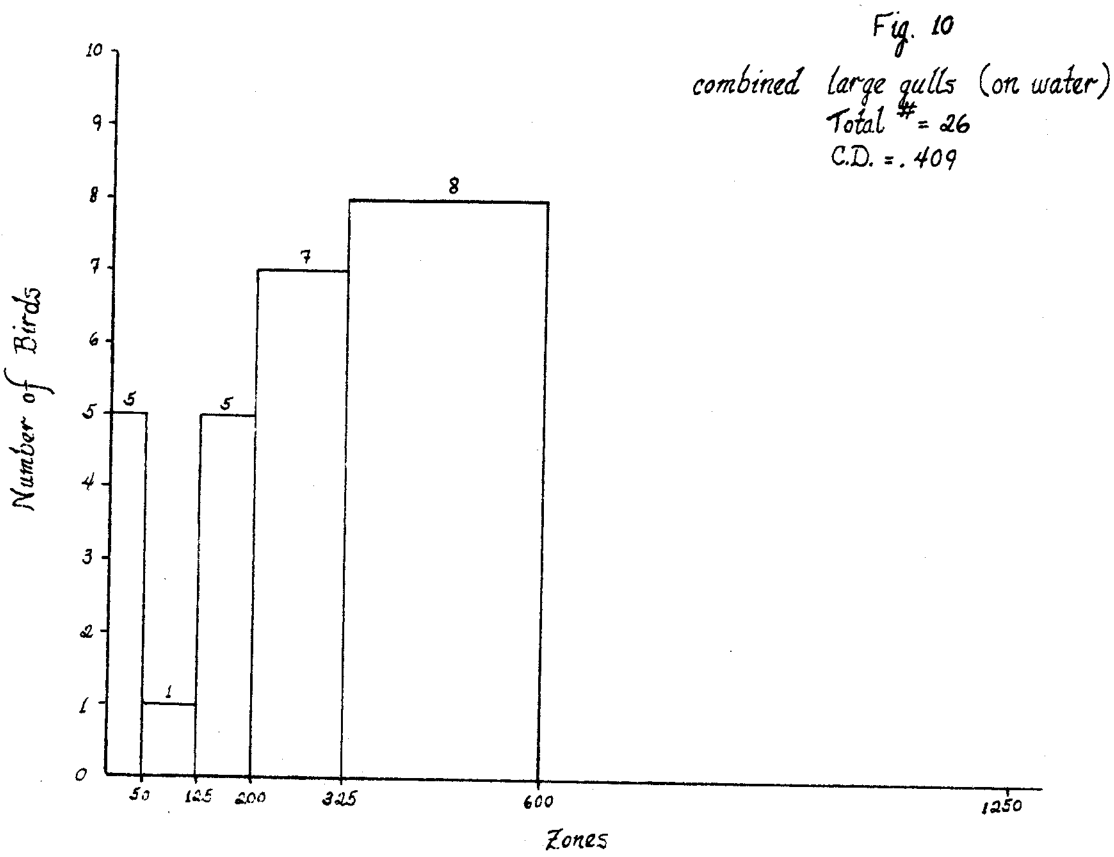


Fig. 10
combined large gulls (on water)
Total # = 26
C.D. = .409
Number of Birds
10
9
8
7
6
5
4
3
2
1
0
5
1
5
7
8
50
125
200
325
600
1250
Zones

Fig. 11

Black-legged Kittiwake (flying)
Total #= 374
C.D. = .342

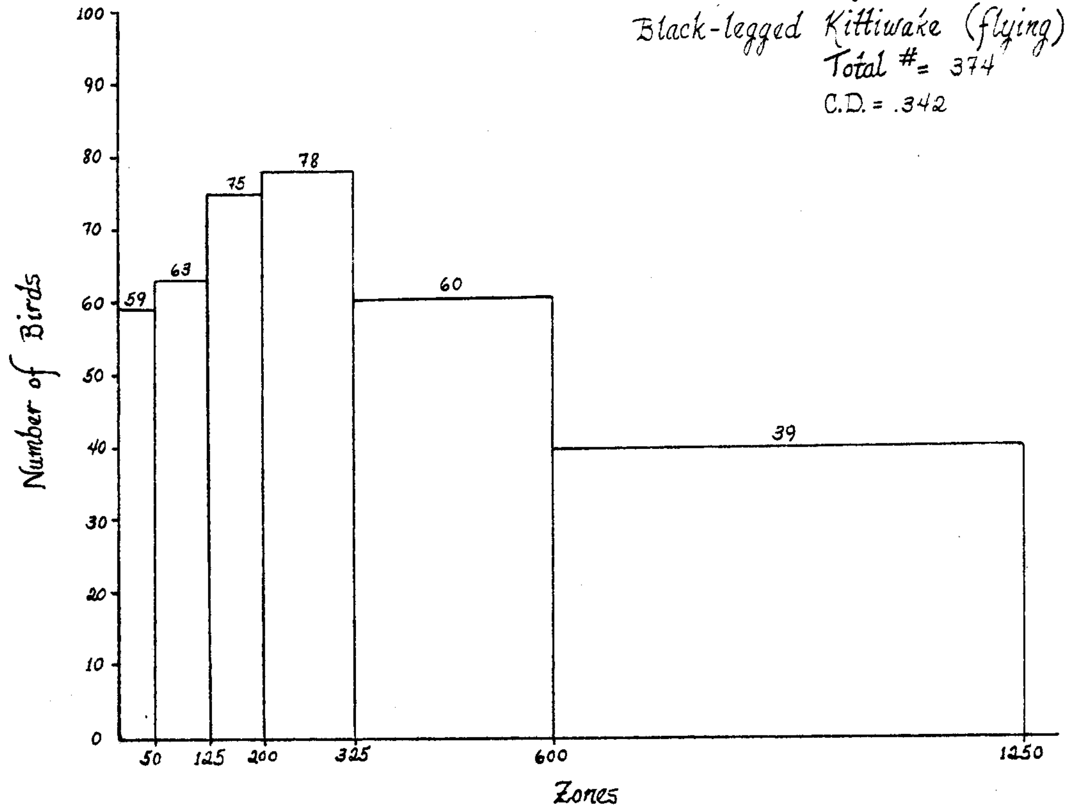


Fig. 12

Black-legged Kittiwake (on water)
Total #= 17
C.D. = .113

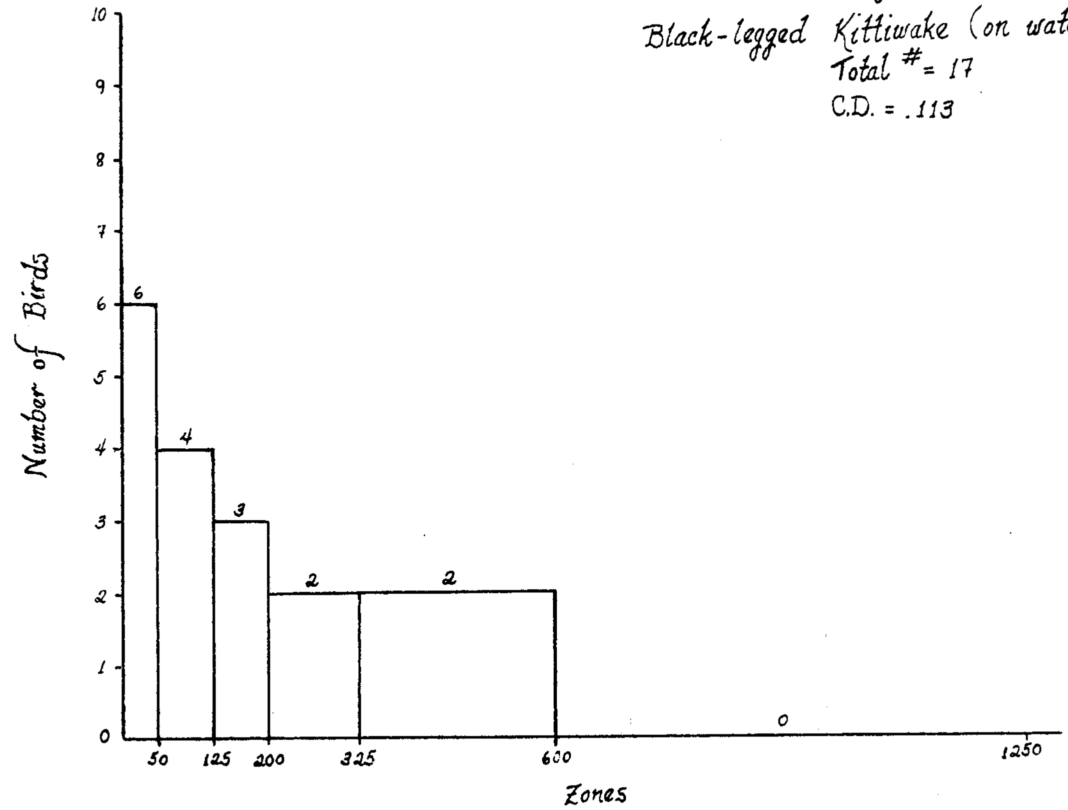


Fig. 13
combined murres (flying)
Total #= 290
C.D. = .357

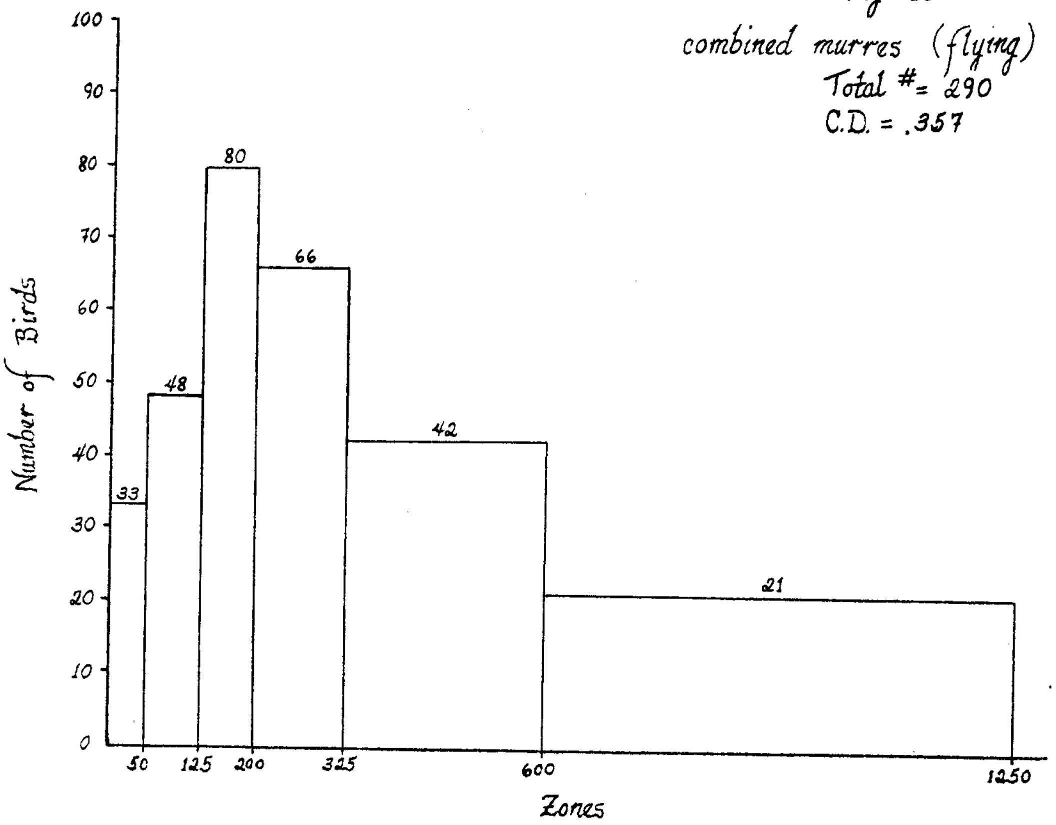


Fig. 14
combined murres (on water)
Total #= 104
C.D. = .269

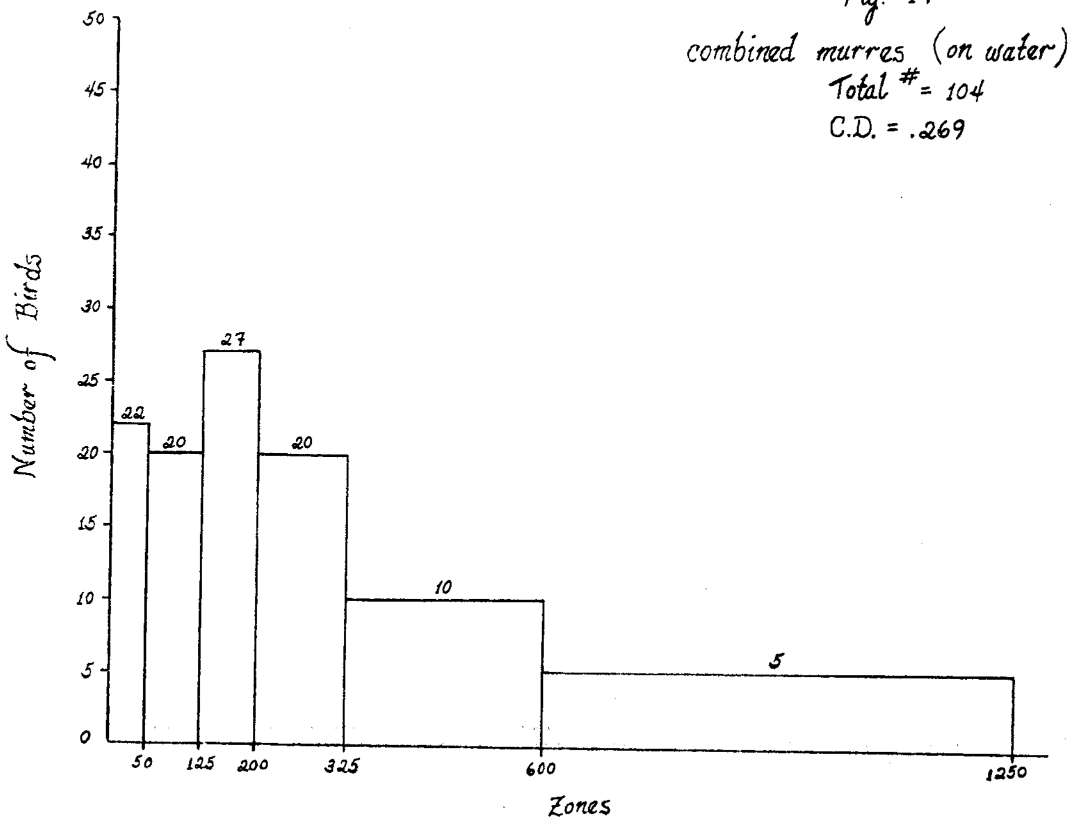


Fig. 15
Horned Puffin (flying)
Total # = 73
C.D. = .518

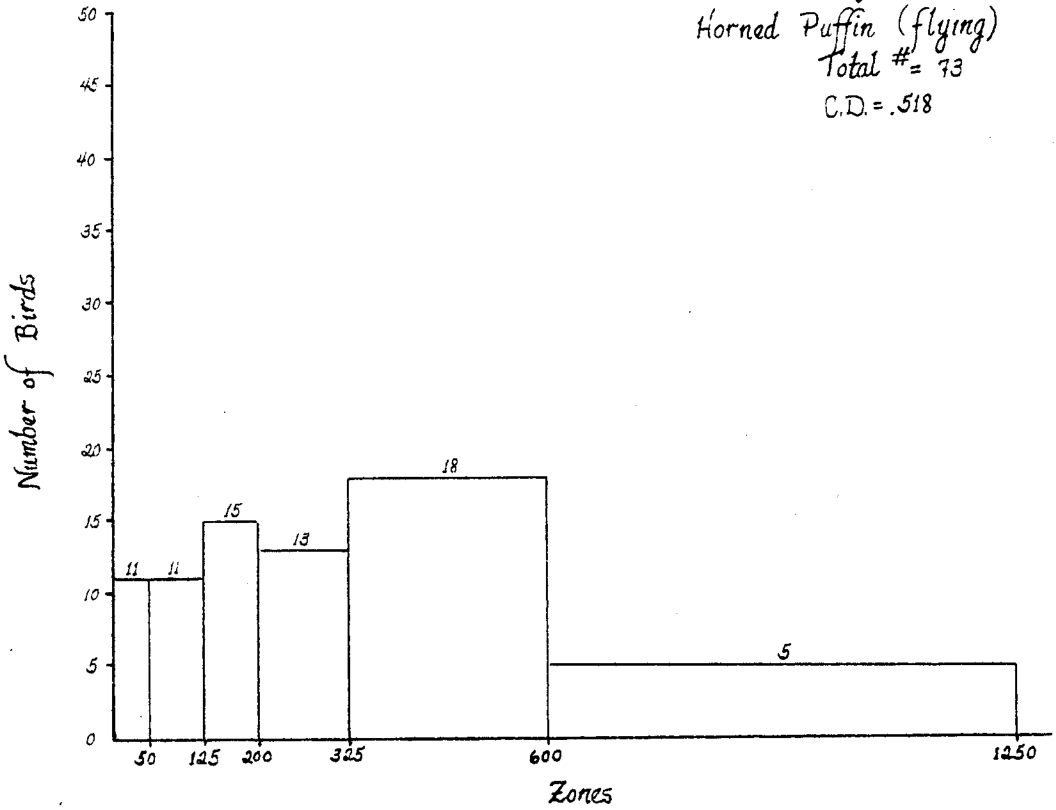


Fig. 16
Horned Puffin (on water)
Total # = 68
C.D. = .101

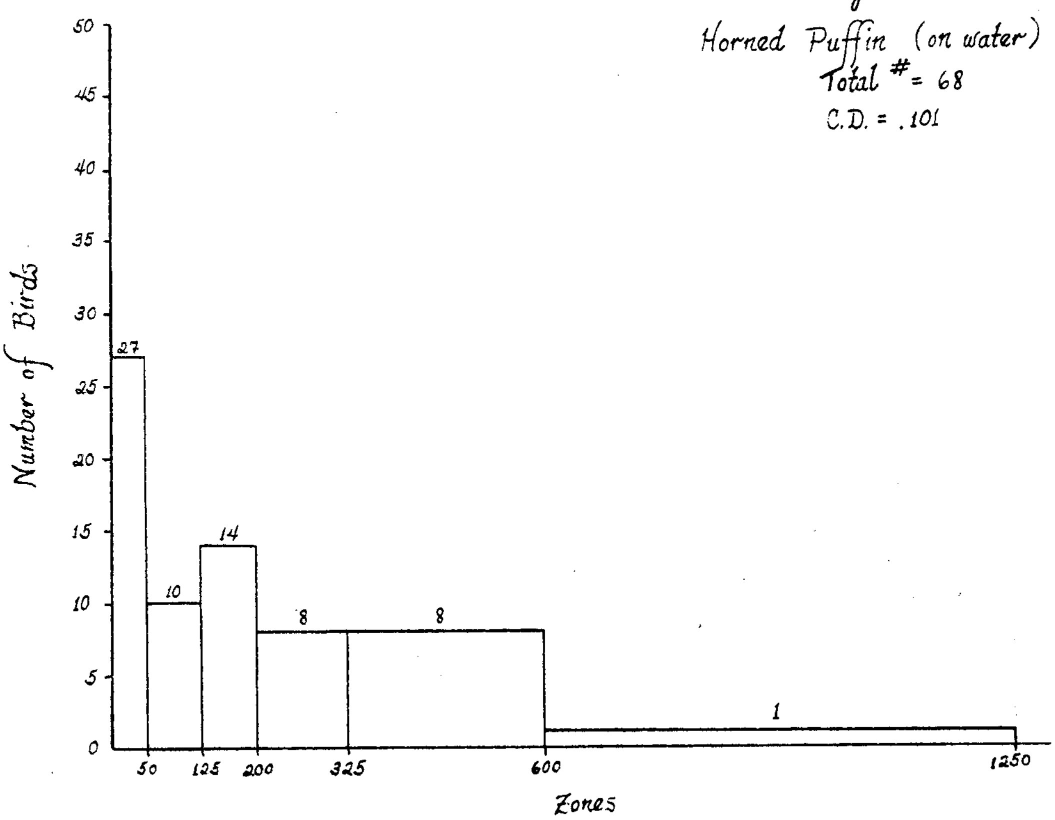


Fig. 17
Tufted Puffin (flying)
Total # = 446
C.D. = .495

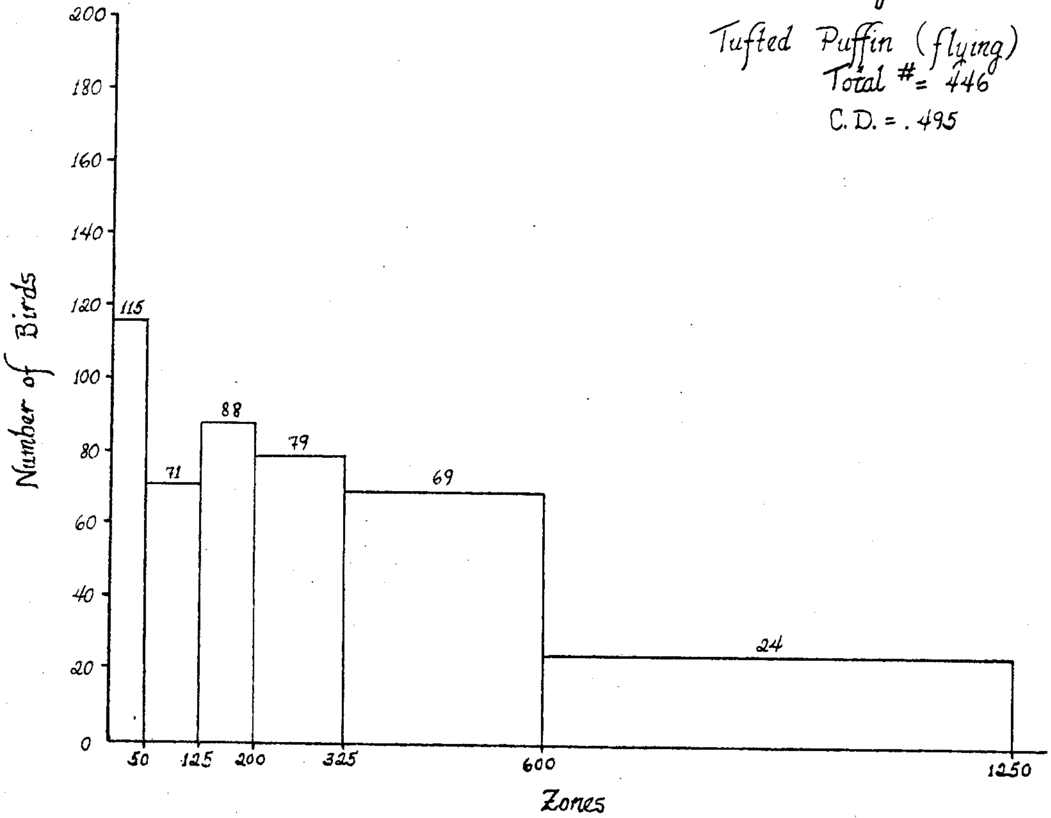
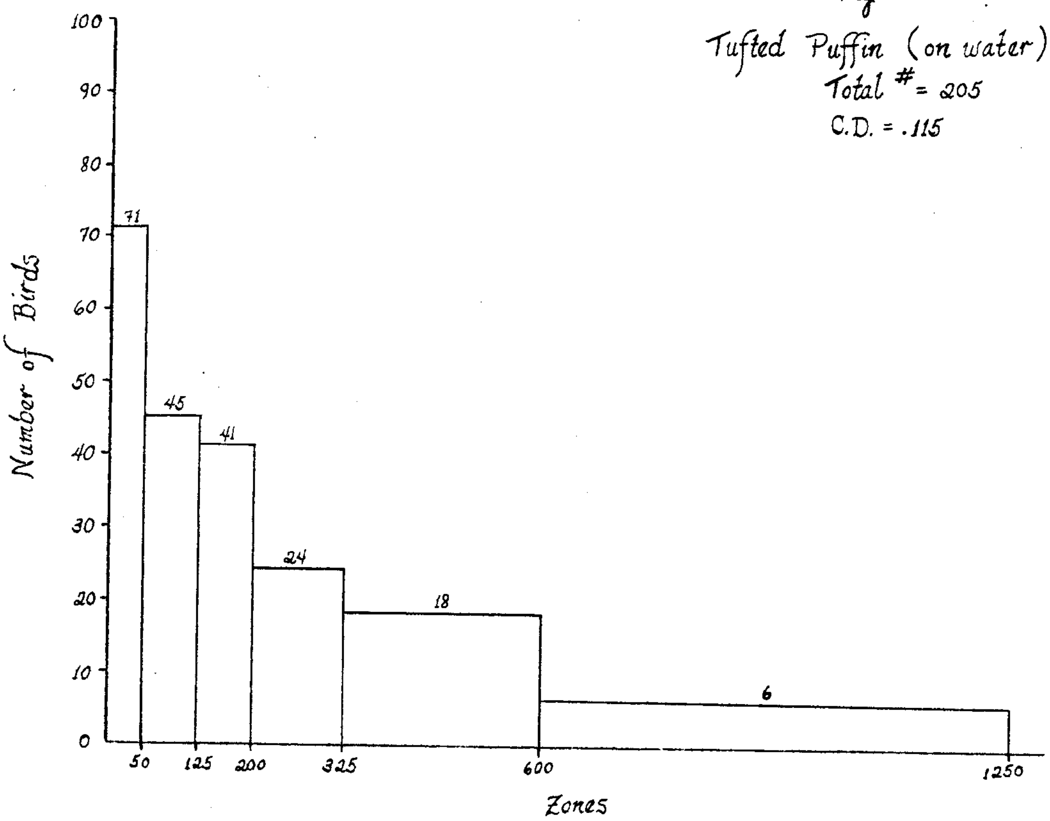


Fig. 18
Tufted Puffin (on water)
Total # = 205
C.D. = .115



The method of derivation of C.D.'s is after Emlen (1971). The method assumes that sightings are independent. As many species are commonly observed as flocks we calculated densities as the product of flock densities and average flock size, where all sightings are taken to be flocks of size one or greater. Where sample sizes permit and detection curves are different we calculate transect densities for birds of a given species, on the water and flying. The density for that species is given by the sum of the on-the-water and flying densities. Similar partitioning can be performed by any of the variables affecting the detection curve; we are currently investigating the effect of sea and atmospheric conditions on the detection functions.

Problem Situations

At times situations arise where the collection of all the data desired is unfeasible or impossible. This section describes a scheme designed to obtain the best possible information on bird density under adverse conditions.

At times the density of birds in an area may be so great that many birds are missed while collecting and recording the desired data on each individual seen. Therefore, when densities are very high the less essential data on each sighting should be omitted. Species, numbers, distances, and directions to the birds are of the highest priority. When there is a regular, dense movement of one species through an area, individuals of other less abundant and less obvious species may be missed. In such cases, the numbers of the most common species can be counted for a short period, in a defined area, such as within 500m of the ship, and a rate per minute recorded. Then the numbers of that abundant species need not be counted as long as they appear to remain relatively constant, and the time can be devoted to recording the other birds present. In such situations the information collected can be abbreviated by dropping detailed behavioral observations, recording flight directions only occasionally to show general trends among groups of sightings and recording as a single observation all birds of species within a single zone, with a brief description of their directions. This sacrifices information on the sequential relationships of sightings of birds within the minute, but improves accuracy of the density estimation.

Another class of problem situations arises when conditions are unsuitable for use of the rangefinder. This is the case in restricted waters such as bays and fjords where the astronomical horizon is frequently obstructed by land. At times it may be possible to use this situation to advantage; if the course of the ship can be plotted accurately, and if all birds can be counted from the ship to one bank, the area covered in a transect can be measured on a chart with a planimeter. Otherwise, distances must be estimated without the use of the rangefinder. It should be noted that distant land rising from behind an oceanic horizon can be ignored; the apparent base of the land mass is used as the horizon.

When the horizon is obscured by fog or precipitation, the rangefinder cannot be used. In addition, certain atmospheric conditions lead to marked visual distortion of the horizon, so that the rangefinder cannot be used accurately. Rain showers and fog are obvious, but horizon-distorting atmospheric conditions may be more difficult to identify. Sawatsky and Lehn (1976) describe the "arctic mirage" and state that it is a common phenomenon in temperate and arctic areas, especially over water or ice. "Arctic mirages" occur during extreme temperature inversions, when atmospheric refraction of light causes the observed horizon to be appreciably above the astronomical horizon, and distant objects are vertically distorted. Apparently the inversions are most common in morning, but they sometimes last into afternoon. The inversions apparently only occur under clear skies. If any land, or any other vessels are visible at a distance of at least several km, arctic mirage conditions should produce recognizable vertical distortion. Objects beyond the horizon which are approached will appear suddenly, and will appear to float just above the horizon. If the ocean surface is choppy, wave crests may appear momentarily detached and distorted. The observer in arctic or cold temperate seas should watch for visual distortion of the horizon, and also beware of very clear mornings when the air temperature is warmer than the water temperature.

Since the rangefinder is used largely as a tool for calibration of the observer's ability to estimate distances, an experienced observer should be able to safely forego use of the rangefinder and depend upon his acquired ability to estimate distances when conditions are unsuitable for rangefinder use.

The interaction of birds with the ship causes problems for censusing. Avoidance interactions are treated automatically in the analysis but if the peak observed density for a species occurs at a distance where birds are being missed, density may be systematically underestimated. This is sometimes a problem with small alcids such as Marbled and Kittletz's Murrelets and with some storm petrels.

When birds are attracted to the ship more serious analytical problems occur. Tufted Puffins will frequently approach a ship, circle it once or twice, and leave. These birds should be left out of the calculation of coefficients of detection.

Other birds, such as Albatrosses, Fulmars, several species of gulls, and tropicbirds may follow ships for extended periods of time, remaining normally behind the ship but occasionally moving up to circle it. These birds should be counted at the beginning and end of each transect, but ignored if they move up from behind the ship into the transect arc. Sanger (1970) has developed a method for estimating turnover rates of ship-following species. The numbers of each ship-following species are counted at regular intervals (in our case at the beginning and end of each transect). The sum of the net increases between adjacent counts is obtained, and added to the initial count. Whenever a count is lower than the preceeding one, the difference represents birds which left, so these differences are then added to the total. This number is a conservative estimate of the overall number of birds involved in following the ship during the period.

Many of the ship-following species are variable in plumage, so distinctive individuals can be noted and if they disappear, added to the turnover total.

The method suffers from one serious flaw: when the ship's garbage is dumped overboard (or an attractive item of flotsam is passed) many if not all of the ship-following birds will settle on the water to pick it over, and will rejoin the ship later. If a count is made in the meantime, the turnover rate and thus density calculated, may be seriously inflated. The method is also difficult to employ on research vessels which are frequently stopping for stations. Nevertheless, it appears to be the best method available for handling ship-followers.

LINE TRANSECT METHODOLOGY

In general, pelagic bird censusers have reported bird numbers as relative abundances, which are expressed as numbers per unit time. When numbers have been reported on an area basis, there has been no attempt to correct for the biases involved in estimating densities (see Eberhardt 1968, Anderson et al. 1976). Whenever the problems of making such corrections have been examined, they have been considered insurmountable, given the resources at hand (Bailey and Bourne 1972, Brown et al. 1975). We propose to examine in detail the problems involved in the estimation of bird densities at sea.

Although abundance measures are useful for tracking spatial and temporal changes in the number of individuals of a given species or community in a given area, density estimates are also required in the study of energetics, population dynamics, and community dynamics. More importantly, in the context of this report, the effects of oil drilling, transportation, and potential spills on bird populations can be assessed only if area- and time-specific density data are available.

Obviously some sampling scheme is necessary, as complete enumeration at sea is impossible, even over very small areas, due to the extreme vagility and/or diving behavior behavior exhibited by most species. Since the definition of plot boundaries at sea is nearly impossible, we are left with the line transect sampling method. Our discussion will be limited to the problems encountered by ship-board censusers using this technique.

Line Transect Theory

A line transect can be conceptualized as an observer moving through a field of birds, recording those that are detected on one or both sides of the transect line (Fig. 19). (The treatment here will assume detection on

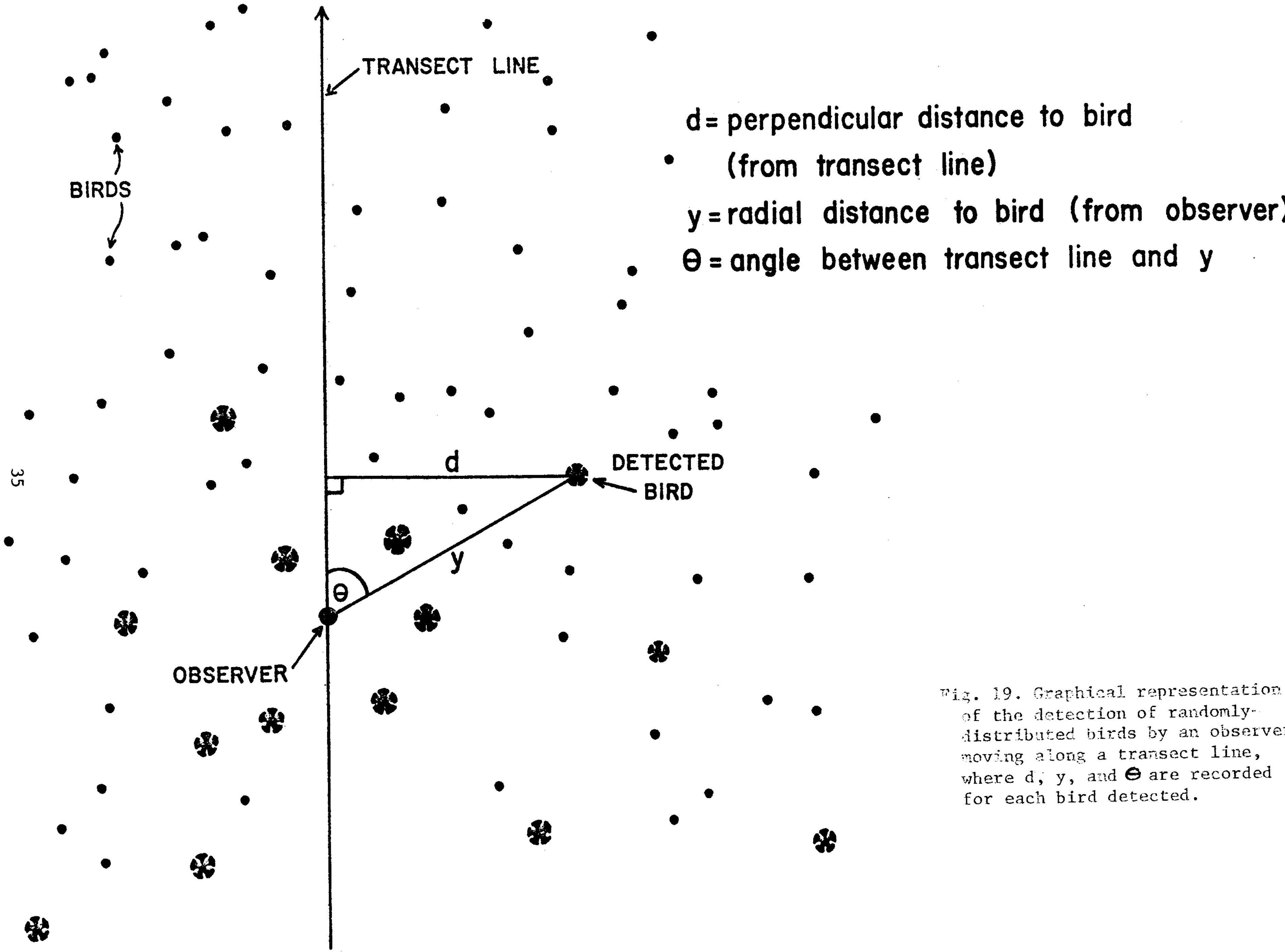


Fig. 19. Graphical representation of the detection of randomly-distributed birds by an observer moving along a transect line, where d, y, and θ are recorded for each bird detected.

only one side.) With this and other information, one can estimate the density of birds in the area sampled. If the population parameters (in the statistical sense) of interest are known, the density (D) is given by

$$D = N/LW$$

where N = number of birds in the area, L = transect length, and W = transect width (LW = area sampled). In practice we are forced to estimate these parameters. The transect length (L) usually does not present any problems. Rarely are the biases involved in its measurement, and with modern navigation equipment the precision of its measurement is so high compared to other errors that its contribution to the variance of the density estimate is negligible.

The crux of the problem is the estimation of N. Rarely will an observer detect all of the birds in the area sampled; consequently, N will nearly always be underestimated. Typically the probability of detecting a bird decreases in some manner as the distance from the observer to the bird increases. One example of a possible form of this relationship (a detectability curve or function) is shown in Fig. 20. Therefore, if one were to substitute n, the number of birds detected, for N, the estimated density ($\hat{D}$) would be underestimated in most cases.

Two concepts are important to this discussion. First, we are looking for a density estimator that will produce estimates that are unbiased and precise. The bias is a measure of the accuracy of the estimates--specifically, that the expectation of $\hat{D}$ equals D, where "expectation of $\hat{D}$" is the same as saying "the average of a large number of independent estimates of D". Precision refers to the variance of a sample of density estimates, with low variance inferring high precision. Ideal density estimators have high precision (minimum variance) and are unbiased.

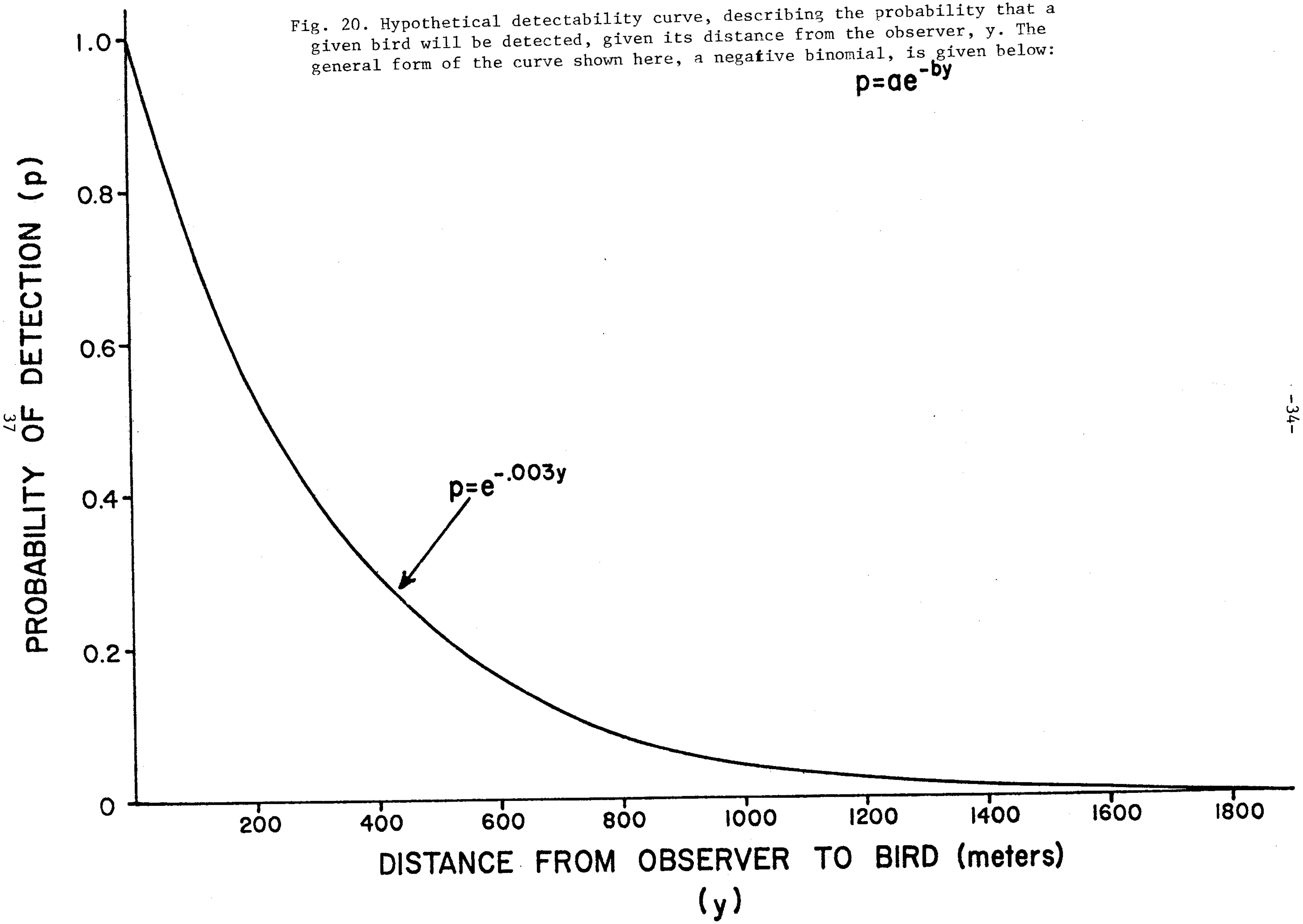


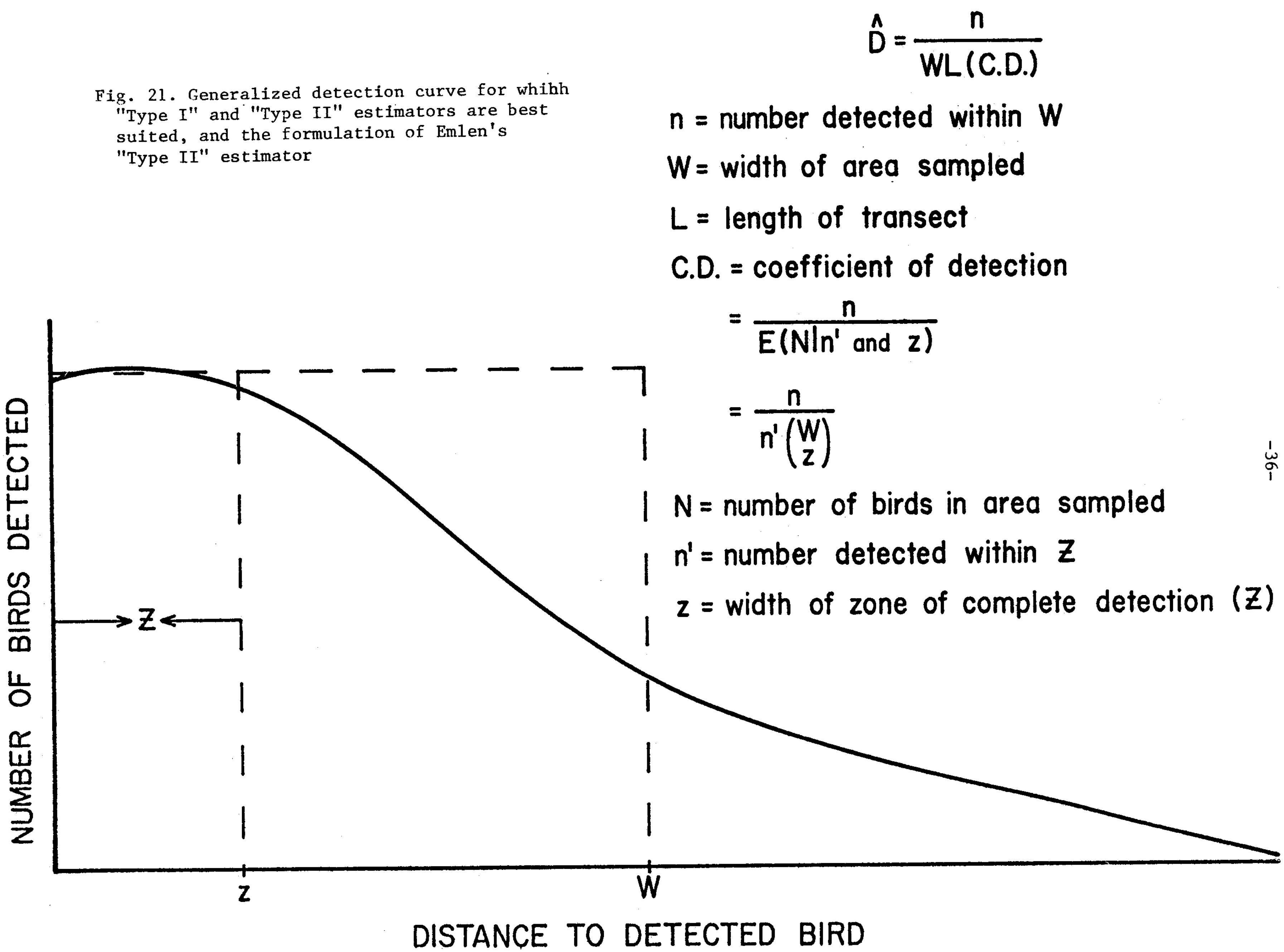
Fig. 20. Hypothetical detectability curve, describing the probability that a given bird will be detected, given its distance from the observer, y. The general form of the curve shown here, a negative binomial, is given below:

$$p=ae^{-by}$$

Two solutions to the underestimation of N are immediately apparent. First, W is chosen arbitrarily; therefore, it can be made small enough that the difference between N and n results in an acceptable bias. This is especially feasible in cases where the detectability curve shows a plateau near the transect line as in Fig. 21, where W would be taken to equal z. The most serious problem with this approach is that the precision of $\hat{D}$ is dependent on n, such that the transect length must be increased in proportion to the reduction in W in order to obtain a reasonable n. Eberhardt (1968) pointed out that, when a random (Poisson) distribution of individuals is encountered, the precision of $\hat{D}$ is proportional to the square root of n; thus, it becomes inefficient to ignore a portion of the population. Anderson et al. (1976) recommend that the transect width be as large as possible (∞), so as to maximize n for any given transect. Estimators of this form will be referred to as "Type I" estimators; examples have been derived by Kelker (as described by Robinette et al. [1974]), Myrberget (1976), and Frye (Overton 1971).

"Type II" estimators (Fig. 21) are similar to "Type I" estimators, but they sample beyond the zone Z, and are thus able to use shorter transects. Birds are detected out to some limit W. From a large number of transects run under similar conditions, a detection curve (i.e., the number of birds detected versus their perpendicular distance from the transect line, d--see Fig. 19 note the distinction between the detection curve and the detectability curve described above) is constructed. A zone, Z, is identified in which it is assumed that all birds are detected. Then the number that would have been detected out to W if detection had been complete for all $d \leq W$ is calculated from the number detected in Z, n', and the ratio of $W{:}z$. The ratio of n to the projection of N from n' forms what Emlen (1971) calls

Fig. 21. Generalized detection curve for whihh "Type I" and "Type II" estimators are best suited, and the formulation of Emlen's "Type II" estimator



a "coefficient of detection" (C.D.). The C.D. can then be used to correct an independent "raw" density estimate made under similar conditions. The limitations here are that (1) it is necessary to know the appropriate C.D., which requires prior sampling, and (2) the assumption of "similar conditions" may not be tenable. The application of a C.D. calculated from one transect to that transect reduces the estimator to a "Type I" estimator. Often the C.D. is applied to the transects that were used to calculate the C.D., rather than to an independent sample. In this case the estimator will have the same mean as a "Type I" but will be more precise. "Type II" estimators have been proposed by Anderson and Posphala (1970), Emlen (1971), and Järvinen and Väisänen (1975).

The second approach tries to compensate for the difference between n and N by adjusting W in the equation. The density is estimated in this case, "Type III" estimators, by

$$n/LW_e$$

where W_e, the effective width, is some central measure (e.g., arithmetic, geometric, or harmonic mean) of the detection curve. In other words, birds are sampled to W, and a W_e is sought such that the number of birds detected beyond W_e will exactly equal the number missed within W_e (Fig. 22). The expectation of n will then equal N for the area LW_e. Gates (1968, 1969) has shown the arithmetic mean of the detection curve to be the appropriate choice when the form of the detectability curve is a negative binomial. Others have taken different approaches and proposed different forms for W_e (Hayne 1949, King, in Leopold 1933). Sen et al. (1974) assume that detectabilities follow a Pearson Type III distribution, and derive estimators using the square of n instead of n and the sum of the distance instead of some W_e (however, see Anderson et al. 1976). This might be called a "Type IV"

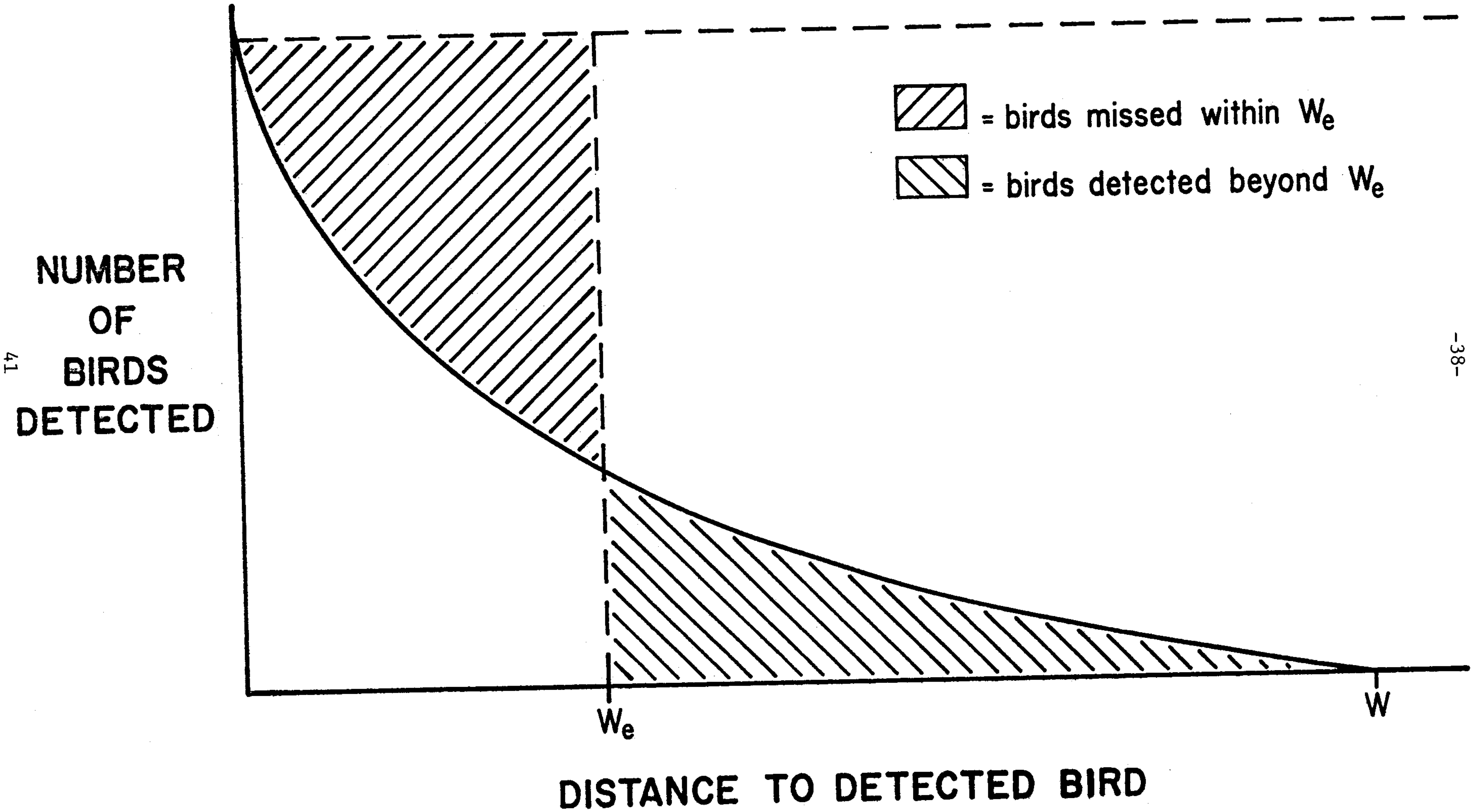


Fig. 22. Graphical representation of the relationship between the area under the detection curve beyond W_e and the area above the detection curve within W_e, as described in the text.

estimator. This discussion is not meant to completely survey the estimators available, but rather to aquaint the reader with the logic and the mathematical form involved. Separate approaches (see Caughley 1972, 1974, 1976; Skellam 1958) are worth looking at, but will not be considered here.

Note that when birds are sampled on both sides of the transect line, the formulas presented above should include a 2 in the denominator since the sampling width has been doubled. It should be noted that "Type II" estimators always use perpendicular (to the transect line) detection curves, whereas some "Type III" estimators use perpendicular detection curves while others use radial (to the observer) detection curves. Burnham and Anderson (1976) have shown that density estimation from the distribution of y alone is not possible. Knowledge of the joint probability density function (p.d.f.) of y and d is required, specifically where $d = 0$. Their treatment assumes that detection is a function of the observer's actions. When the model of Hayne (1949) is considered, where detection is a function of the animal's response (flushing) to the observer, the p.d.f. is deriveable and their result reduces to Hayne's estimator. They then suggest a correction factor to be applied to the Hayne estimator based on the expectation of the angle to the bird, θ.

For all of these estimators, the accuracy and precision of their estimates is maximized when the following conditions are true:

1) The birds are distributed randomly (independently).
2) The probability of detection, given y, is uniform over the entire length of the transect for all individuals. (Some estimators make assumptions about the form of the detectability curve which must hold.)
3) Detections are independent.

4) There are no measurement errors.

5) The probability of detection at $y = 0$ is one.

6) Birds do not move, and are detected only once.

When these "ideal conditions" hold, some estimators have been shown mathematically or by simulation to be unbiased (Gates 1968, 1969; Robinett et al. 1974; Myrberget 1976; Kovner and Patil 1974). Further, Kovner and Patil (1974) have shown that among those that are unbiased the Gates (1969) radial estimator is superior because it has the smallest variance. When the first four conditions are not met, the precision will generally decrease, and the accuracy may occasionally be affected. We now consider each of the necessary conditions in more detail.

Random distribution of birds.--The first assumption is that the birds are distributed at random in the area being sampled. In other words, the position of any one bird is independent of the position of any other bird. It is important to note that this implies that the birds are also distributed independently of the transect line. A random distribution is just one of many distributions on a continuum from uniform (regular) to highly clumped (aggregated, patchy, or contagious) (Poole 1974). Therefore, given a large enough sample size it will always be possible to reject a hypothesis that a population is randomly dispersed. The deviation from randomness that is of interest here is a clumped distribution, as uniform distributions are rare at sea, and because precision increases with regularity (Eberhardt 1968). In general, density estimates of patchily distributed populations suffer a decrease in precision (Eberhardt 1968). However, as clumping can occur on several different scales, the magnitude of the decrease is a function of the length of the transects relative to the patch sizes. Biases can result when the placement of transects is non-random with respect to the patch structure of the population.

<u>Probability of detection</u>.--In general, the probability of detecting a bird, p (see Fig. 21 and 22), decreases in some manner with y. Some estimators make the assumption that the detectability curve is of a certain form, such as a negative binomial (Gates 1968, 1969) as shown in Fig. 20 (the generalized form used by Gates is shown in the upper righthand corner; a is assumed to equal one), or a Pearson Type III distribution (Sen et al. 1974). In any case it is always assumed that the detectabilities are the same for all members of the population. If W_e varies within the population, the precision will decrease; if the distribution of W_e is skewed, a bias will be introduced.

<u>Independent detections</u>.--The third assumption is violated when the detection of one bird leads to the detection of others. This can occur when the birds are distributed in a nonrandom fashion--the most obvious example being small scale clumping that we refer to as flocking. No bias will be introduced in this situation as long as transects are randomly placed with respect to flocks, but precision will decrease in proportion to the mean flock size. Gates (1969) has shown an increased variance for flock sizes of two in his simulation work. Further, the detectability curve is a function of the flock size, so that where there is variation in flock size within a transect the second condition will also not be true.

<u>Measurement errors</u>.--Errors in the measurement of any of the parameters of an estimator will result in a larger variance of $\hat{D}$, but as long as measurement errors are not systematic, no biases will be introduced. Gates (1969) has shown that the former is true when errors are allowed in the measurement of y and d.

Deviations from ideal conditions 1-4 do not appear to be particularly serious. It appears that biases should be uncommon and can be handled with a well designed sampling scheme. Increasing the number of birds detected per transect and the number of transects will tend to offset decreases in precision due to nonconcordance with these conditions. However, nonconcordance with assumptions 5 and 6 seems likely to introduce serious biases as well as to decrease the precision.

Probability of detection on transect line.--Given that an estimator is unbiased under ideal conditions, if the probability of detection is less than one on the transect line, then the true density will always be underestimated. In the case of the "Type I" and "Type II" models, this assumption must hold true for $0 \leq d \leq z$.

Bird movement.--The sixth assumption is that the birds do not move. It seems that the density estimates should increase as bird velocities increase since more birds will be encountered in a given area than would be were they not moving. This may or may not involve counting the same individuals more than once.

At sea rarely are any of the ideal conditions met; therefore, field and analytical methods are needed to minimize the errors just discussed. In the following text we describe tests of the effect of what we consider to be the most serious source of error, bird movement, using computer simulation. The results of that work along with similar work on other sources of error in the literature can be used to suggest useful methods of density estimation at sea.

The Simulation Model

We have designed a computer simulation model to test the effect of various deviations from ideal conditions on density estimators of the form given earlier. We are able to assess the accuracy of each estimator under a given set of conditions by comparing its mean from a sample of independent, random transects to the true density (which, in a simulation, is known). The precision is assessed by comparing some measure of the sample variances of the different estimators.

The model consists of a square field of specified size. Birds are emitted from any one-meter interval on either the x or y axis (i.e., either the bottom or the left side of the field respectively) at set or variable velocities, angles, and frequencies. Once on the field, velocities and directions are fixed or allowed to vary in a random or a nonrandom manner (e.g., ship attraction or avoidance can be simulated). At a designated point in the field, there is a detection locus (i.e., observer) around which occurs a detection region (i.e., field of view). The locus is assumed to be on the transect line and oriented in one direction along the line. The birds are moved in discrete time steps of specified length.

The birds are allowed to move about on the field until an equilibrium density is achieved, where equilibrium is defined as a change in the number of birds on the field of less than half the number of birds entering thre field per step for three consecutive steps; that is, equilibrium is reached when the number of birds entering the field is approximately equal to the number leaving. A transect is begun at this point and is terminated after either a specified number of steps or after a specified number of birds has been detected. At the end of each step the instantaneous density in the detection region is determined as the number of birds in the region divided by the area of the region. Birds detected within the detection region are flagged; hence, each bird not previously detected potentially can be. At the end of each step, each undetected bird is subjected to a Bernoulli trial, the outcome of which is either detection or non-detection, where the probability of detection is specified by an arbitrary detectability function, conditional on y. The instantaneous density, the variables used by the estimators (i.e., y, d, and θ), and the number of birds detected are accumulated during the transect. At the end of each transect, means and variance measures, where possible, are printed for the instantaneous density, for the estimator variables, and for the density estimates. Further, frequency histograms are printed for the estimator parameters. The histogram for perpendicular distances, d, is used to compute the Type II estimates, which must be calculated by hand. A generalized flow diagram of the model is given in Fig. 23.

Independence of the transects is insured by running the birds a few steps beyond the end of each transect before beginning the next, so as to clear out the birds that were in the detection region after the last step. After a set number of transects have been run (i.e., a sample), the same information printed for each (means, variance estimates, and totaled frequency histograms) is summarized for the sample and printed. Also at this stage, the density estimates are expressed as a percent of the true density, and the outcome of a paired t-test (true versus estimate) is printed for each estimator.

The model was primarily designed to simulate bird movements, which have been assumed to be negligible in most theoretical treatments and tests of transect theory. By adjusting the velocity and direction of the birds' flight, we are able to simulate any combination of bird and observer movements. For instance, an observer moving at 10 m/s through a field of motionless birds is simulated by moving the birds parallel to the transect

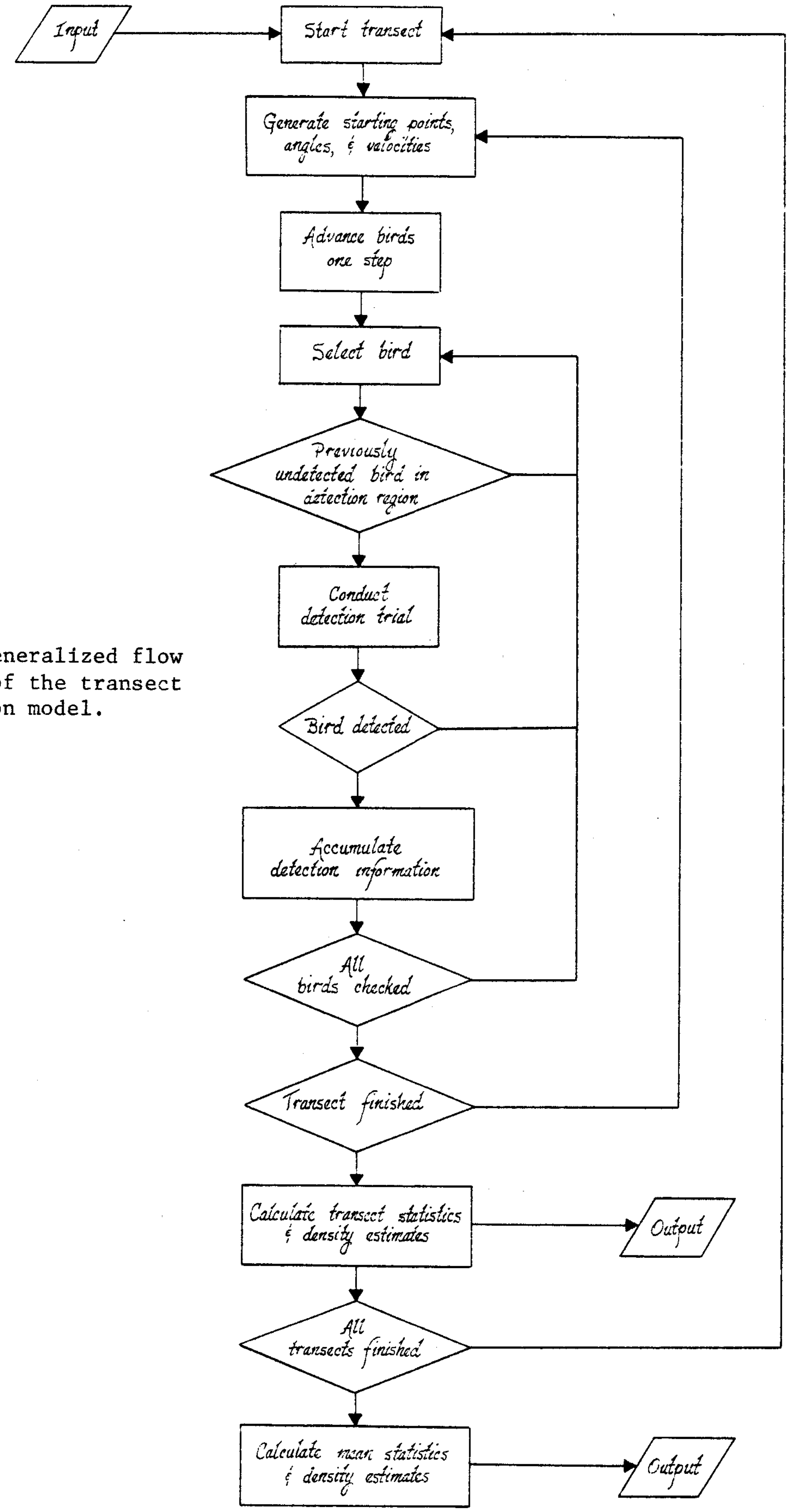


Fig. 23. Generalized flow diagram of the transect simulation model.

line in the opposite direction of the locus' orientation at 10 m/s. Combinations of velocities and directions can be simulated by moving the birds at the velocity given by the equation for their velocity relative (*RV*) to the observer,

$$RV = \sqrt{b^2 + s^2 - (2bs)\cos\theta}$$

where b = the birds' velocity, s = ship's velocity, and θ = the angle between the two (parallel movement is defined as a θ of 180). The angle between the transect line and the relative velocity vector is then computed using trigonometry.

Simulation Results

Although the program was designed to test the effect of bird movement on density estimation, it is capable of testing any of the assumptions of the line transect models discussed earlier. We initially wished to test the effects of six distributions of relative bird movements; however, programming problems have prevented us from completing all of the tests at this date. The work that has been completed is more extensive than originally proposed.

In the simulations to be discussed here, the following features were always constant:

1) The field was 2,000 x 2,000 m.
2) All birds were emitted and traversed the field at a fixed velocity and angle for any given run (i.e., sample of transects).
3) They were emitted at a constant frequency, with the point of emission being chosen at random along either or both (independently) sides.

4) The detection region was a quarter circle (Fig.27), with the observer at the center of the circle (radius = 1,250 m). This simulated an observer on a ship with a field of view from dead ahead to 90° to one side of dead ahead.

5) The time step was 10 s.

6) The transects were run until approximately 120 to 150 birds had been detected.

7) The probability of detection (p) was given by $p = e^{-.006y}$.

The estimators tested are shown in Fig. 24. The Burnham and Anderson estimator is the corrected Hayne estimator discussed earlier. The "raw" estimator is included to show how seriously n underestimates N. The simulations were conducted under ideal conditions except that movement of the birds was allowed. For the simulations conducted, the simulated velocities, relative angles and velocities, sample sizes, mean numbers detected, true densities, and estimated densities (as percentages of the true densities) are shown in Table 1. The first set, simulations 1 through 4, were conducted under completely idealized conditions, but at different observer speeds. For the moment, discussion will be limited to these simulations. It is immediately obvious that very few of the estimates are unbiased (the underlined values). Three patterns are discernible at first glance. First, all of the estimates in simulation 1 are highly positively biased. Second, at equal densities (simulations 2 and 3) a doubling of the ship's velocity reduces the estimates an average of 35%. The mean density for all estimates at 6 m/s and 83.9 birds/km^2 (simulation 3) is not significantly biased at the 95% level. On an individual basis, three estimators are unbiased at 6 m/s, while only one is unbiased at 12 m/s. Third, at a constant velocity a doubling of the true density (simulations 3 and 4) results in slightly less than a doubling of the estimates for all of the estimators.

Fig. 24. The estimators, their sources, and formulations as used in the simulations

Estimators	Sources	Formulas
King	Leopold (1933)	$\hat{D} = n/L\bar{y}_A$
Hayne	Hayne (1949)	$\hat{D} = n/L\bar{y}_H$
Gates II	Gates (1969)	$\hat{D} = (2n-1)/L\bar{y}_A$
Gates III	Gates (1969)	$\hat{D} = n/L\bar{y}_G$
Webb	Webb (1942)	$\hat{D} = n/L\bar{y}_G \sin\bar{\theta}$
Gates I	Gates et al. (1968)	$\hat{D} = (n-1)/L\bar{d}$
Yapp	Skellam (1958)	$\hat{D} = n/\bar{y}_A TV$
Burn. & And.	Burnham & Anderson (1976)	$\hat{D} = c(n/L\bar{y}_H)$
Emlen	Emlen (1971)	$\hat{D} = n/LW(CD)$
FWS	personal comm.	$\hat{D} = n''/LW''$
raw	——	$\hat{D} = n/LW$

Where: $\hat{D}$ = estimated density in birds per square kilometer
n = number of birds detected
L = length of transect in kilometers
$\bar{y}_A$ = arithmetic mean of radial distances (km)
$\bar{y}_H$ = harmonic mean of radial distances (km)
$\bar{y}_G$ = geometric mean of radial distances (km)
$\bar{\theta}$ = arithmetic mean of sighting angles (deg)
$\bar{d}$ = arithmetic mean of perpendicular distances (km)
T = length of transect in seconds
V = relative velocity (km/sec)
$c = (1-\delta) + \delta(2/\pi)$ where $\delta = (\bar{\theta} - 32.7)/(45 - 32.7)$
W = width of transect (1250 m in this case)
CD = Emlen "coefficient of detection"
n'' = number of birds detected within 300 m
W'' = 300 m

Table 1. The simulated velocities of the birds and observer, the relative velocity and angle of flight of the birds, the number of transects conducted, the mean number of birds detected, and the mean and standard deviation of the true density describe each transect. The density estimates are given as their percentage of the mean true density, which is a measure of their accuracy

Simulation	Velocity (m/sec)		Relative Angle (deg.)	Relative Velocity (m/sec)	Number of Transects	Mean (n)	True Density (#/km^2 ± SD)	Density Estimates (% of True Density)										
	Ship	Birds						King	Hayne	Gates II	Gates III	Webb	Gates I	Yapp	Burn. & And.	Emlen	FWS	raw
1	1	0	0	1	3	340	201 ± 2.67	137	167	274	148	211	228	137	128	162	132	68
2	6	0	0	6	20	128	83.9 ± 2.67	98	149	195	117	147	161	98	106	109	92	34
3	12	0	0	12	10	131	82.7 ± 1.34	69	116	137	85	101	109	69	81	80	62	21
4	12	0	0	12	10	138	41.5 ± 0.91	75	137	150	95	109	121	75	92	84	67	22
6	6	10	225	4.94	10	171	140 ± 5.61	122	292	242	171	173	206	148	189	97	100	33
7	6	4.6	45	6	10	155	115 ± 4.71	110	165	219	131	153	170	110	102	109	94	36
8	6	12	180	6	10	122	81.3 ± 1.90	126	255	251	171	152	158	126	79	108	91	33
9	6	9	90	6.71	10	119	74.3 ± 2.22	106	163	212	128	149	166	95	101	114	96	36
10	6	9	270	6.71	10	130	73.6 ± 2.61	124	236	247	165	207	234	111	206	108	114	34
11	6	12	135	6.95	10	145	98.3 ± 3.83	139	311	278	188	178	201	120	135	121	110	39
12	6	12	225	6.95	10	140	98.4 ± 3.58	148	334	295	205	210	248	128	215	116	101	32
13	6	6	45	8.49	10	119	79.0 ± 3.28	128	213	256	155	184	204	90	138	126	114	40
14	6	6	315	8.49	10	127	79.3 ± 3.26	145	293	288	192	219	236	102	217	134	124	36

In simulations 6 through 14, the effects of the angle of flight can be seen. At a constant relative velocity there seems to be very little difference in the effect between 0° and 45° (simulations 2 and 7). Figure 25 compares the actual numbers detected by zones (0-100, 100-200, 200-300, 300-500, 500-800, and 800-1,250 m) to those expected (given the detectability curve) for simulations 2, 7, and 9 in which the flight angles range from 0° to 90° (see Fig. 27). The observed differs significantly from the expected in all except the second zone. Figure 26 shows the observed and expected numbers (all significantly different by t-test, $p<.05$) for simulations with angles of 135° to 315° (see Fig. 27). The effect of angle can be seen in the different pattern of deviation (Fig. 25) of observed from expected for birds entering the field by crossing its curved boundary (0°-90°) versus birds crossing the straight (radial) boundaries (135°-315°; Fig. 26).

Most of the patterns seem to reflect the manner in which the relative velocity affects the resulting measure of the detection function (i.e., $\bar{y}$ or $\bar{d}$). For instance, birds entering the field at a 45° angle to the transect line (i.e., crossing the curved boundary) will have a larger $\bar{y}$ or $\bar{d}$ than will birds entering at 225°. The difference will increase as the relative velocity increases, because as velocity decreases the number of chances to be detected (the number of steps that the bird remains in the detection field) increases. This results in birds' being detected earlier at slow speeds than at high speeds. Thus at angles 135°-315° (Fig. 26) many more than expected are detected in the first three zones, and consequently fewer than expected are detected in the outer three zones. Figure 25 should show the opposite pattern, but it is modified slightly. More birds than expected are detected in zones 3 and 4 with fewer in the first zone. This approximately follows the predicted pattern but we are unable to explain why fewer instead of more were detected in zones 5 and 6.

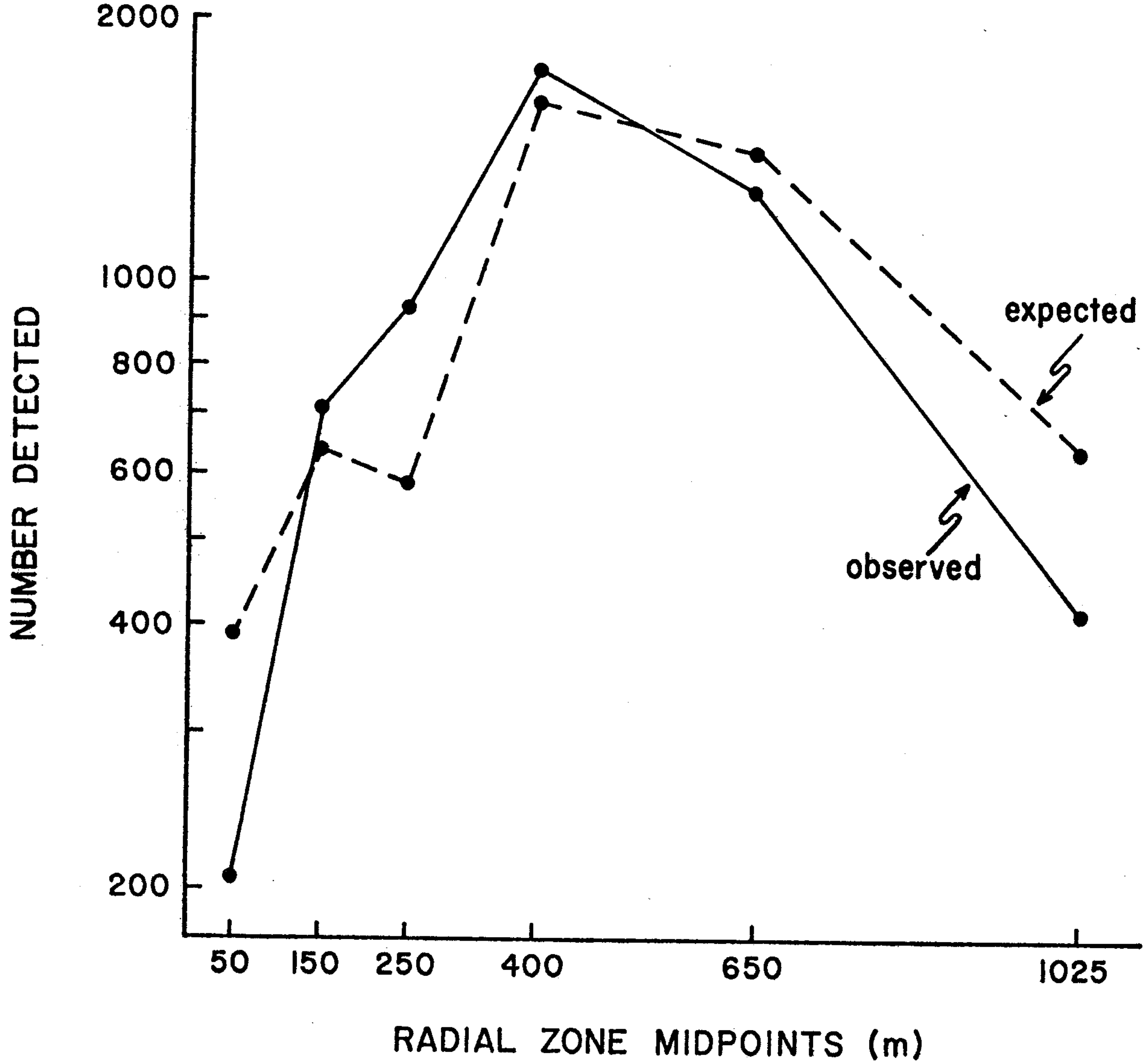


Fig. 25. The observed and expected numbers of birds detected in radial zones, given no angle or velocity effect, in those simulations where the angle of flight was between 0^{o} and 90^{o}

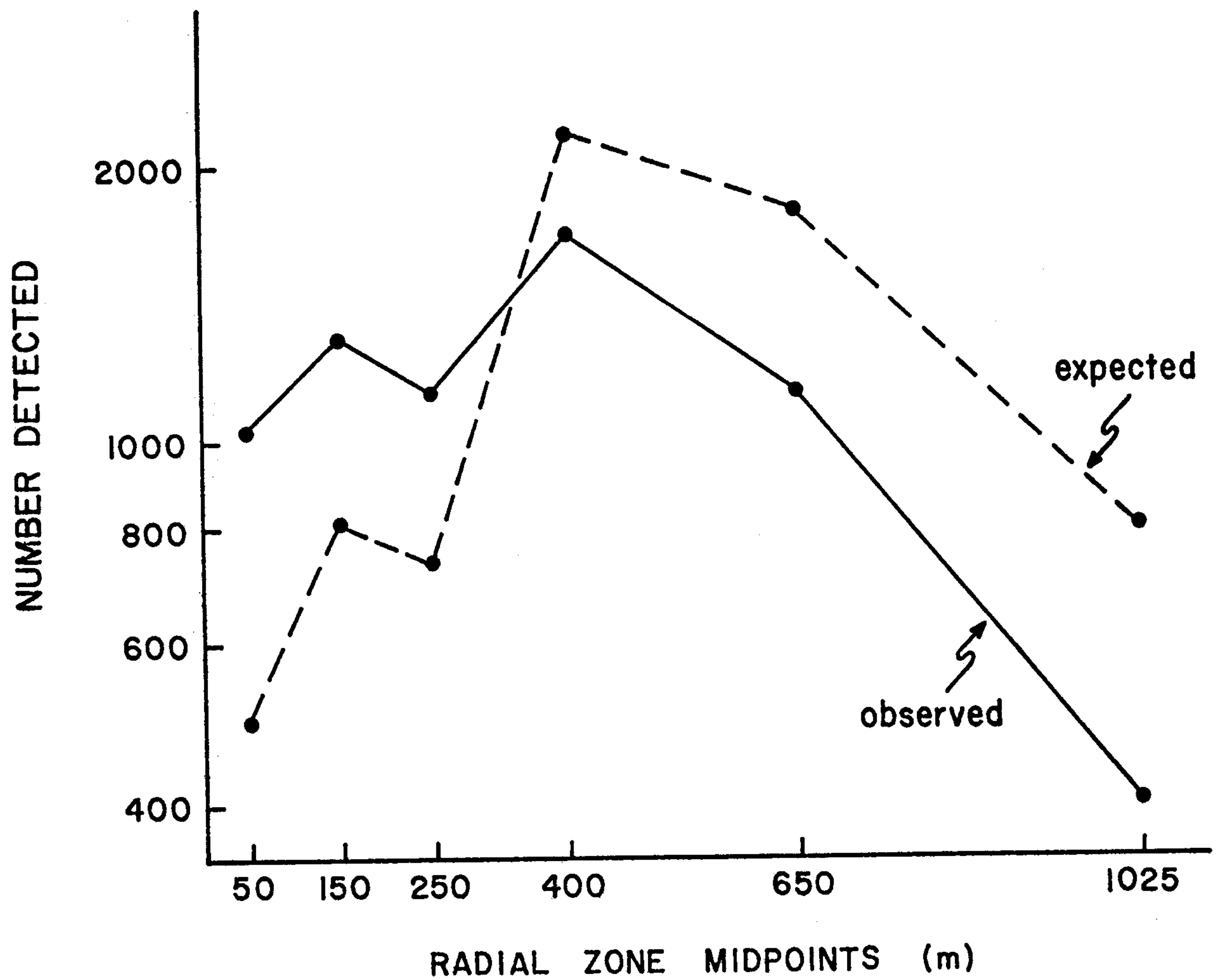


Fig. 26. As Fig. 25, but for those simulations between 135° and 315°

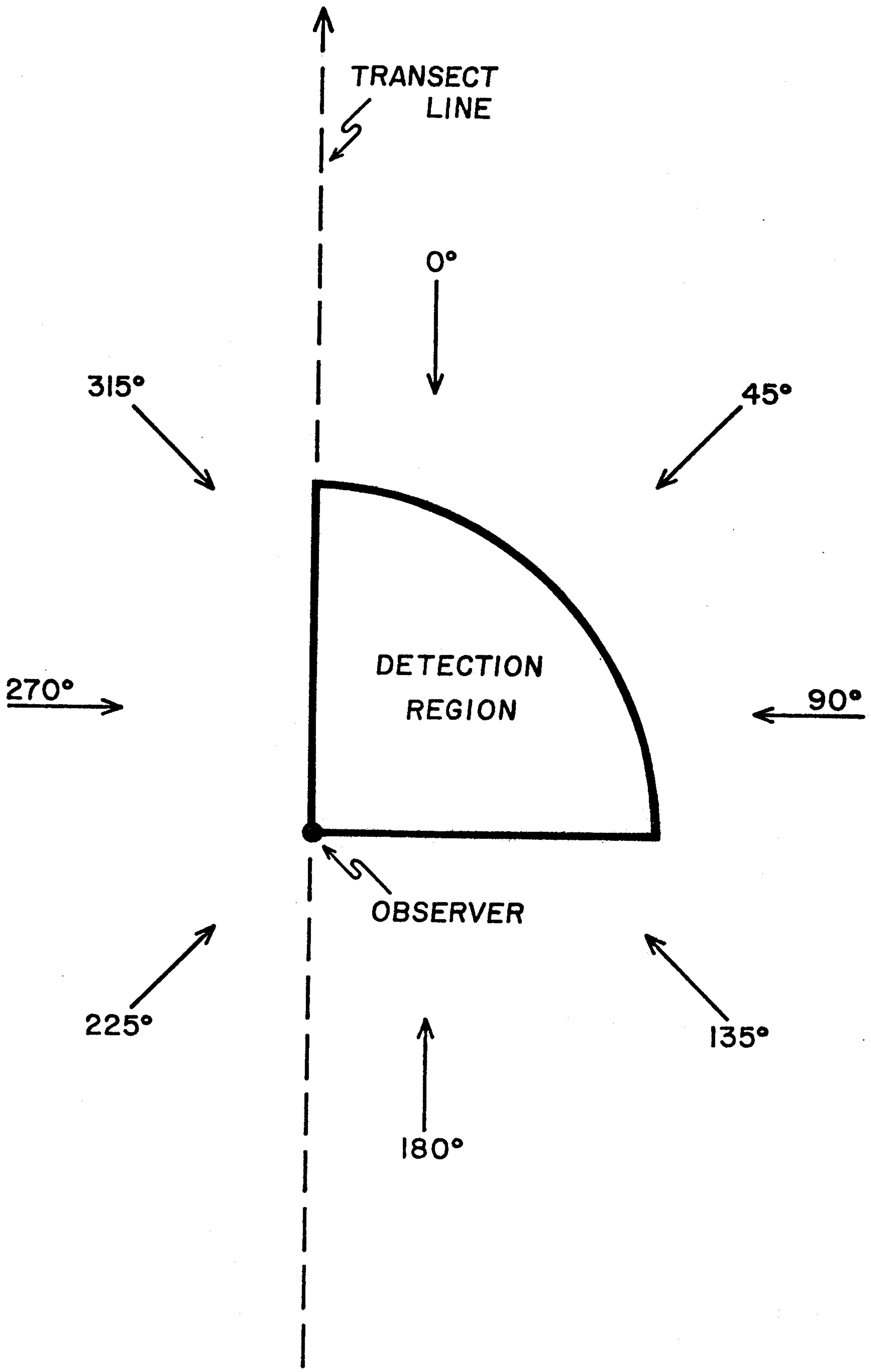


Fig. 27. A diagramatic representation of the observer's detection region in relation to the transect line and the directions of the birds' flight

Specifically, the only time that the difference is zero is when the birds reside in the field for only one step; here the angle should no longer have an effect.

This led us to believe that we might be able to correct for the biases by accounting for the variability in the estimates due to relative velocity and angle. We found that for each estimator, linear regressions of the estimated density on the true density, velocity, and a measure of the angle effect were very highly significant, sometimes accounting for as much as 99% of the variation in $\hat{D}$. However, as we have been unable to derive a good measure of the angle effect from the field data, we have dropped this variable from the regression. The greatest amount of variability can be accounted for with the following model:

$$\hat{D} = aV^b D^c$$

where D = the true density, V = relative velocity, $\hat{D}$ = estimated density, and a, b, and c are regression coefficients. Linear regressions were run on the following linear transformation of the model:

$$\ln \hat{D} = a + b \ln V + c \ln D$$

This model was chosen over others because it came the closest to perfectly correcting $\hat{D}$ (i.e., making the slope [c] equal one and the y-intercept [a] equal zero). In most cases the y-intercept was not significantly greater than one, although one was very close (c = 1.025 for Emlen).

From these models we were able to generate corrected density estimators ($\hat{D}'$) of the following form:

$$\hat{D}' = e^{-a/c} - (b/c)V + 1/c\ \hat{D}$$

where e is the constant 2.718. Table 2 shows the mean bias for all the estimators and corrected estimators and the significance level (difference from true density) for each for all simulations except number 1. Every $\hat{D}$ is significantly positively biased, except for "raw" which does not have a

Table 2. The average bias for all simulations of each estimator before $\hat{D}$ and after $\hat{D}$ correction, as described in the text

	$\hat{D}$		$\hat{D}'$	
Estimators	% of D	Significance	% of D	Significance
King	117	$p < .001$	101	$p > .5$
Hayne	224	$p < .001$	103	$p > .5$
Gates II	233	$p < .001$	101	$p > .5$
Gates III	152	$p < .001$	102	$p > .5$
Webb	166	$p < .001$	101	$p > .5$
Gates I	186	$p < .001$	102	$p > .5$
Yapp	110	$p < .001$	101	$p > .5$
Burn. & And.	140	$p < .001$	118	$p < .001$
Emlen	109	$p < .001$	101	$p > .5$
FWS	100	$p > .5$	101	$p > .5$
raw	54	$p < .001$	101	$p > .5$

detectability decay factor (e.g., W_e or C.D.), which is negatively biased. After correction only one of the estimators is significantly biased. Most importantly, the corrected "raw" estimate is also unbiased. Further, it appears that $\hat{D}'$ (raw) also is the most precise. Table 3 shows the coefficients of variation for the original and corrected estimators (with the CV's for the true density removed) for all simulations except number 1.

When the regression is used to correct each simulation separately, the results are not as neat (Table 4). More individual estimates than before (Table 1) are unbiased, but the majority are still significantly biased. In general, it appears that the perpendicular estimators (Types I and II, Webb, and Gates I) perform better than the radial estimators. The results specifically indicate that the Emlen, "raw," Yapp, FWS, and Hayne estimators might be useful.

Discussion

These results suggest that estimates of bird densities at sea must take into account the relative velocities and angles of flight of the birds. Flight speeds for many species are much faster than 12 m/s (up to 20-25 m/s). Preliminary results suggest that severe underestimations may result at high velocities, although the angle effect does decrease. At present, we are unable to explain this deviation, having argued previously that bias should go to zero when velocities are such that the birds are in the field during only one step (in these simulations this would be at velocities of greater than 125 m/s). The range of simulated velocities (1 to 12 m/s) equals 2.2 to 26.8 mi/h. A realistic range of bird velocities at sea might be 10-40 m/s or 4.5-17.9 mi/h. The relative velocities could range from near zero to perhaps 30 m/s; thus, within the range of reasonable relative velocities, moderately large biases (up to 50%) may arise even using the

Table 3. The mean precision for all simulations of each estimator before (upper row) and after (lower row) correction as described in the text. Precision is expressed as the coefficient of variation (CV) of the estimated density minus the CV of the true density

<u>Estimators</u>

	King	Hayne	Gates II	Gates III	Webb	Gates I	Yapp	Burn. & And.	Emlen	FWS	raw
Mean of the CV($\hat{D}$) - CV(D)	.062	.125	.061	.078	.072	.080	.071	.156	.046	.061	.044
Mean of the CV($\hat{D}'$) - CV(D)	.044	.075	.044	.049	.055	.058	.051	.092	.044	.049	.030

Table 4. Same as Table 1, but the density estimates have been corrected as described in the text.

Simulation	Velocity (m/sec) Ship	Velocity (m/sec) Birds	Relative Angle (deg.)	Relative Velocity (m/sec)	Number of Transects	Mean (n)	True Density (#/km² ± SD)	Density Estimates (% of True Density) King	Hayne	Gates II	Gates III	Webb	Gates I	Yapp	Burn. & And.	Emlen	FWS	raw
2	6	0	0	6	20	128	83.9 ± 2.67	80	80	88	84	91	90	93	101	98	93	97
3	12	0	0	12	10	131	82.7 ± 1.34	76	70	75	76	75	74	87	84	84	77	78
4	12	0	0	12	10	138	41.5 ± 0.91	92	101	92	95	90	93	106	116	84	89	88
6	6	10	225	4.94	10	171	140 ± 5.61	91	106	91	96	93	96	106	128	84	90	83
7	6	4.6	45	6	10	155	115 ± 4.71	90	78	90	85	90	89	94	89	98	90	99
8	6	12	180	6	10	122	81.3 ± 1.90	108	117	108	113	94	90	113	83	97	92	96
9	6	9	90	6.71	10	119	74.3 ± 2.22	91	86	91	90	89	90	88	100	97	93	94
10	6	9	270	6.71	10	130	73.6 ± 2.61	111	116	111	114	126	128	108	168	100	117	101
11	6	12	135	6.95	10	145	98.3 ± 3.83	116	128	116	118	107	107	108	114	111	111	114
12	6	12	225	6.95	10	140	98.4 ± 3.58	122	135	122	126	123	127	112	159	108	119	110
13	6	6	45	8.49	10	119	79.0 ± 3.28	117	108	118	111	118	118	96	125	121	122	126
14	6	6	315	8.49	10	127	79.3 ± 3.26	129	134	130	130	137	132	105	171	128	132	133

better estimators, and very large biases (up to 200%) may result using the poorer ones. The true densities used are at the upper end of the range of densities we have encountered in Alaska. The comparison made earlier between simulations 3 and 4 suggests that it may be important to simulate lower densities. More simulation work is being conducted to determine the exact relationship between the estimated density and the relative velocity and angle of bird flight over the entire range of reasonable velocities and densities.

It is important to examine how representative of field conditions, in terms of bird movements, these results are. As already pointed out, the simulated velocities did not cover the full range of expected velocities, but the range was sufficiently large to suggest that velocity can cause serious inaccuracies. The complete range of possible relative angles was simulated, but all simulations were unidirectional. Typically birds are observed flying in several directions. Our field data suggest that the detectability function (negative binomial) used is most applicable to birds on the water or to small flying birds. Large flying species may have detectability curves more like that shown in Figure 21. We expect that different curves will affect the pattern of the relationship between estimated density and relative velocity but not necessarily the severity of the effect of the latter on the former. The effect of relative velocity on density seems to be a function of different degrees of repeated sampling of the same population without replacement, in proportion to the velocity and time step. The time step is directly analogous to the sweep rate of the observer's eyes in the field. Ten seconds is a reasonable rate, although the rate varies tremendously in the field.

Recommendations: Analytical Method

Recommendations will be presented as part of the discussion of six "ideal" conditions appearing in the section on theory. These suggestions will be based upon considerations of sampling theory, tests of density estimators in the literature, and our simulation results.

Random distribution of birds.--The reduction of variance and bias when sampling patchily distributed populations is a problem in survey design. In general, uniform distributions do not present problems, except when the number of individuals per transect approaches one (Pielou 1974). When sampling a randomly distributed population, the placement of transects is unimportant (Pielou 1974), but such populations are rare in nature. Most of the time the pelagic censuser will be faced with patchily distributed populations. The standard solution is to apply a stratified or two-stage sampling design (Pielou 1974, Poole 1974); however, this requires the ability to identify strata or patches of different densities. This is occasionally possible at sea when densities are related to physical features of the environment, such as sea mounts, islands, current convergences, or the shelf break. In these cases stratified or two-stage sampling can be used as described by Pielou (1974), Poole (1974), or any statistics text on sampling theory. Burnham and Anderson (1976) have shown that at least for "Type II" estimators the strata estimate should be weighted by transect length ($\bar{\hat{D}} = \sum_{i=1}^{r} L_i \hat{D}_i / \sum_{i=1}^{r} L_i$).

When patches cannot be associated with measurable environmental features, stratified or two-stage sampling cannot be employed. This case calls for simple random sampling. Precision can be improved by increasing either the size or the number of transects, although the latter may be more efficient

(Gérard and Berthet 1971). Enlarging the transects tends to increase the number of patches found within a single transect, thus making each transect more representative of the overall density. As transect length decreases, the probability that a transect will occur entirely within a single patch increases, and thus the deviation of any given estimate from the true density will increase. Therefore, the number of transects must be increased to maintain the required precision.

A special case often occurs in pelagic censusing: the observer is not able to choose the placement of his transects. In this case, density estimators whose theoretical variances are known and/or long transects should be used. Sometimes variance estimates can be obtained alternatively by dividing long transects into several smaller transects. In either case, the censuser obtains some estimate of the variance of each density estimate when it is not legitimate to consider a set of such estimates a random sample.

Probability of detection.--The probability of detecting a given bird is a function of the following factors: the observer, the distance from the observer to the bird, the height of each (observer and bird) above sea level, the observation conditions (e.g., amount of sunlight, glare, ship motion, swell, rain, wind), and the bird's behavior, size, color, and proximity to other birds. Whenever the bird factors are different between groups within the population being sampled, the second condition will not hold, and precision will decrease. This is true when a population contains different color or size classes, when some birds are flying and some are sitting on the water, when some birds tend to avoid ships more than others, or when the birds aggregate in flocks of variable size. This type of heterogeneity in a population will decrease the precision of its density estimate. Precision can be regained by using stratified sampling--that is, by letting each group represent a single morphological or behavioral class of the population.

Changes in observational or environmental conditions within a transect will also cause precision to decrease. If the resulting loss of precision is intolerable (e.g., when sampling opportunistically), the transect should be terminated and eliminated from subsequent analyses if the number of birds detected to that point is insufficient. Remember that "Type II" estimators require all transects to be conducted under similar conditions; therefore, it is important to monitor the observation conditions in order to subsequently evaluate how typical each transect was.

Independent detections.--Most species of sea birds flock to some degree. If a flock were detected, and each individual were recorded as a detection at the distance of the flock, the variance of the resulting density estimate would be larger than if independent detections had been made. The obvious solution to this problem is to estimate the density of flocks, where single birds are also considered "flocks", and to multiply this estimate by the mean flock size to obtain the population or class estimate. This will not completely eliminate the loss in precision since there will always be an error associated with the mean flock size. However, by following this scheme potential biases can be controlled by stratified sampling of flock size classes. Anderson et al. (1976) point out that flock density estimation is dependent on the observer's ability to accurately estimate the distance to the geometric center of the flock and that this may not be feasible for species that form loose flocks.

Measurement errors.--The effect of measurement errors cannot be effectively controlled at the experimental design or data analysis stage; therefore, an effort must be made in the field to reduce errors in measurement.

Probability of detection on transect line.--The pelagic censuser is faced with the problem of reducing or correcting the negative biases that arise from incomplete detection on or near the transect line. Complete detection within this region occurs for only the most highly visible species (e.g., albatrosses, white gulls, frigate birds). The most immediate solution is to limit the collection of transect data to periods of optimal observability or to try to obtain independent estimates specifically designed to detect every bird close to the observer (Reynolds et al. 1977), thereby providing a correction factor. Such correction factors are applicable to "Type I" and "Type II" estimators; we have not investigated their applicability to estimator Types III and IV.

Bird movement.--The simulation results suggest that biases due to bird movement can be largely eliminated. Specifically, it seems that densities can be accurately estimated by

$$e^{a/c}V^{b/c}(n/LW)^{1/c}$$

or, in other words, by the correction of the "raw" density estimates (as previously described). If some variable could be found that would account for the angle effect, accuracy would be increased even further. Regression coefficients are provided by the simulation model, but we suspect that they are detectability function specific. We feel that a reasonable approach would be to generate coefficients for a wide variety of detectability curves and then to select the appropriate set, after comparing and matching the field-data-generated detection curves with those generated by the simulations. We presently are attempting to generate and to test such sets of coefficients.

Recommendations: Field Methods

Sampling procedures are somewhat a function of the number of classes and species being sampled, the degree of error one is willing to accept, and the density of birds encountered. The pelagic bird censuser must adapt this analysis to his or her own situation. We cannot suggest a single field method that will be optimal or even adequate in all situations. However, we will outline some of the most important factors to consider.

Foremost in importance is the choice of a survey design. Whenever possible, efforts should be made to establish the required degree of precision and to translate it into a specified number of random or stratified transects. The conclusion of Gérard and Berthet (1971)--namely, that precision is more efficiently increased by increasing the number of transects than by increasing n--is best applied to "Type I" and "Type II" estimators. This is because for these estimators the measure of the transect width is a population estimate based on a large number of observations. For "Type III" and "Type IV" estimators, however, it is based only on the distribution of y's or d's for that transect; consequently, in such cases transect length and number of transects should not be considered equally complementary. We suspect that the precision of each transect will fall off so rapidly below some limit of n that the number of transects necessary to offset the loss in precision will be prohibitively large. Anderson et al. (1976) suggest that this limit is approximately 40 birds per transect. Thus, in many cases (especially for rare species) it may be best to use "Type I" or "Type II" estimators and to run as many relatively short transects as time will allow. These transects should be placed randomly within strata or within the sampling region if strata are not used. Most "Type III" and "Type IV" estimators do have two advantages. First, none requires prior knowledge of the detection curves as do "Type I" and "Type II" estimators. Second, those that use W_e derived from the distribution of y's are more precise. This is because d cannot be measured directly in the field. It is obtained from the estimates of y and θ:

$$d = y \sin \theta$$

A 10% error in the measurement of y and θ will yield approximately a 15% error in d. Preliminary sampling or data from previous surveys can be used to determine the number of transects needed to achieve a certain degree of precision.

There are other factors that bear on the choice of an estimator. "Type I" estimators must employ different transect widths for each species or class, which is a difficult procedure to implement in the field. Alternatively, all species can be sampled to the same maximum width, but this would be very inefficient. Restriction of the transect width, however, is also very inefficient in view of the importance of n to the precision of the density estimate, especially when sampling populations of rare species.

"Type II" estimators require hand calculation of the "coefficients of detection," and as yet there is not an objective way to determine z (Fig. 21). Ship avoidance and attraction and the inflation of the detection curve close to the transect line from birds crossing the transect line into the detection field are all factors that confound the accurate determination of a C.D. Most importantly, the accuracy of any one density estimate is a function of how closely it resembles the average conditions encountered during the transects used to calculate the C.D.

Several of the "Type III" estimators are derived from specific detectability functions. The use of these estimators on data that do not fit the assumed function will give biased estimates (Gates 1969). The arguments of Burnham and Anderson (1976) discussed earlier are important here. Note that their corrected Hayne estimator performed very poorly even after our correction was applied.

Regardless of the choice of estimator, the following parameters must be estimated for each bird detected, at least during the preliminary survey: (1) y, the radial distance to the bird, (2) θ, the angle to the bird, when d is to be calculated, or when Burnham and Anderson's modified Hayne estimator is to be used, (3) V, the velocity of the bird relative to the observer, and (4) α, the angle of flight relative to the observer.

We have developed a rangefinder for use at sea (see description on p. 11) for the measurement of y. To date we have estimated θ by eye to the nearest 15° and have made most of our measurements of y in terms of zones. As this introduces very large errors in the calculation of d and reduces the resolution of the distribution of d's, we recommend point rather than zone measurements of y and θ. Anderson et al. (1976) point out that if data are to be lumped into zones, it can be done more efficiently a posteriori. Velocity and angle of flight are best measured directly by making two or more estimates of θ and y at set time intervals. For one observer to measure each of these variables on each bird detected would be very difficult, even at moderate densities, and would tend to increase the negative bias due to incomplete detection on the transect line. In general, unless two or three observers work together, the precision of the measurement of y, θ, V, and α will suffer. It was consideration of this type of trade-off that led us to decide to sample on just one side of the ship. As was discussed previously, we do not have an adequate means to correct for the negative bias introduced by deviation from 100% detection on or near the transect line. It is obvious that this bias will increase as density increases or as more time is spent measuring each detection. For this reason the "Type II" estimators become more attractive. A team of observers might conduct a large series of highly comprehensive transects to determine the C.D.'s to be used for different species under different conditions. Subsequently, single observers could run transects more efficiently using these C.D.'s, measuring only n within W.

Applications to OCSEAP Research

When sample sizes have permitted it, we have implemented the recommendations given here, except those pertaining to relative velocity. Our field data do not permit the estimation of V, so we have been unable to correct the density estimates presented in this report. The necessity of measuring V was made after our field data had been collected.

The U.S. Fish and Wildlife Service (RU 337) uses a "Type I" estimator that sets W at 300 m for all species. Although the FWS estimator performed well in these simulations, we feel that it was a spurious result. In view of the detectability curve used, the assumption of complete detection in Z is completely untenable. The probability of detection at 100, 200, and 300 m in the simulations, was 0.55, 0.30, and 0.17, respectively. That FWS was not consistently negatively biased was due to the effects of bird movement, which introduced a positive bias. Our experience in the field suggests that the FWS method is unreliable. For some species, 300 m may be a reasonable transect width, but for most species (e.g., small alcids, phalaropes, storm-petrels, small gulls, and many other species when they are on the water) we suggest that it is much too wide. For other species that tend to avoid ships (e.g., Sooty and Short-tailed shearwaters, jaegers, and *Pterodroma*) 300 m may not be wide enough.

Special Problems

In some situations and for some species, density estimation by transects, in general, is not feasible. Several species (e.g., Northern Fulmar, Black-footed Albatross, several larids, and occasionally puffins and storm-petrels) are strongly attracted to ships. This has two effects that tend to bias density estimates. First, they will be detected closer to the ship than their distributions predict; consequently, densities will be underestimated. Second, they will be especially prone to multiple detections, thus introducing a positive bias. In some cases we can proceed with our estimations, hoping that the two biases will be of approximately the same magnitude. However, for those species that follow ships, other methods of density estimation will have to be found. Some species appear to avoid ships at times; such behavior will also lead to underestimates of density. Since we cannot see any way to objectively correct for these biases, we suggest that density estimates be qualified by the observer's assessment of the magnitude of these influences.

In situations of very high densities, the observer may not be able to speak fast enough, when using a tape recorder, or write fast enough to record the number of each species detected, let alone to take data on those detections. This situation is frequently encountered in Alaska. At times, one may see tens of thousands of shearwaters scattered in loose flocks from the ship to the horizon. Obviously other means of density estimation are needed in these situations. We suggest a series of "plot" censuses be conducted close to the ship, where complete detection is assumed. When movement is in one direction, a flow rate for a zone of complete detection can be recorded periodically along with a density estimate based on the total number of birds passing through the area (where area is defined as the width of the zone times the relative velocity times the length of the transect in time).

STUDY AREAS

The studies of marine bird distribution were conducted on the continental shelf and adjacent oceanic areas of the Gulf of Alaska and southeast Bering Sea. Our tracklines for the census cruises are indicated in Figures 28 through 36.

TRANSECT CENSUS RESULTS

The transect-derived densities are pooled within species by 13 time-area blocks (see Fig. 37 for area definition, and Table 5 for time frames and sampling effort). Mean, 95% confidence intervals ($\bar{D} \pm \alpha(2)_{n-1}^{.05}$ SE($\bar{D}$)), and sample size (n = number of transects) are reported for each block by each species (Tables 6-14). For several taxa (shearwaters, jaegers, large gulls, and murres) identification or sample size limitations have prevented us from reporting accurate species densities. We give combined densities for these groups and report density ratios, based on observations that were made to the species level, for Sooty vs. Short-tailed Shearwater (Table 8), Glaucous-winged vs. Herring gulls (Table 11), and Common vs. Thick-billed murres (Table 14).

Overall Seabird Densities (Table 6, Fig. 38)

We calculated overall seabird densities using the total number of birds recorded on the transects in each time-area block with an "average" C.D. of 0.372. This C.D. was obtained as a weighted (by species abundance) mean of all the C.D.s calculated for the various species. This presents one important source of error. If one area has a higher percentage of small, less visible

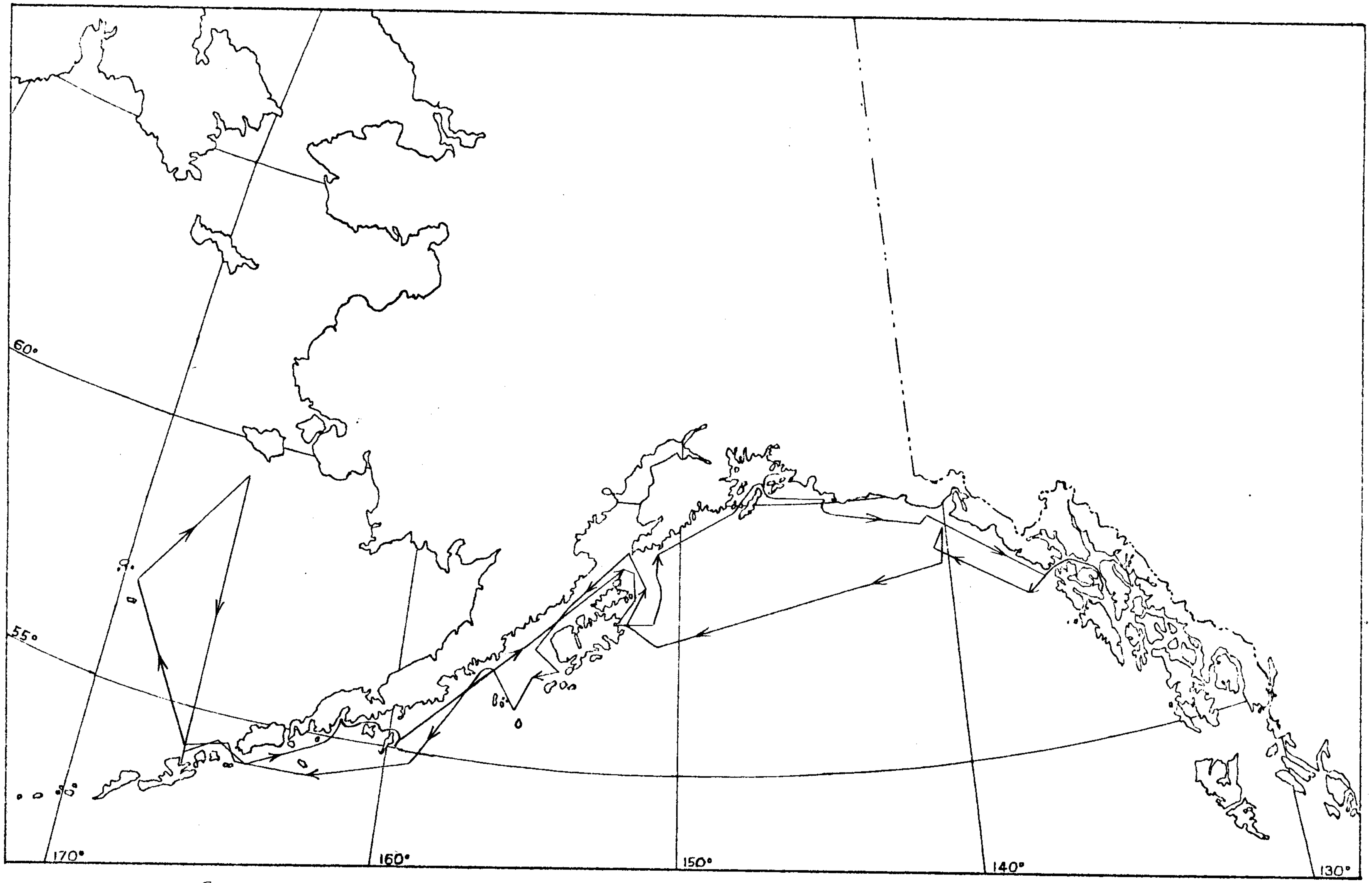


Fig. 28. Trackline of Surveyor, August 8 - September 23, 1975.

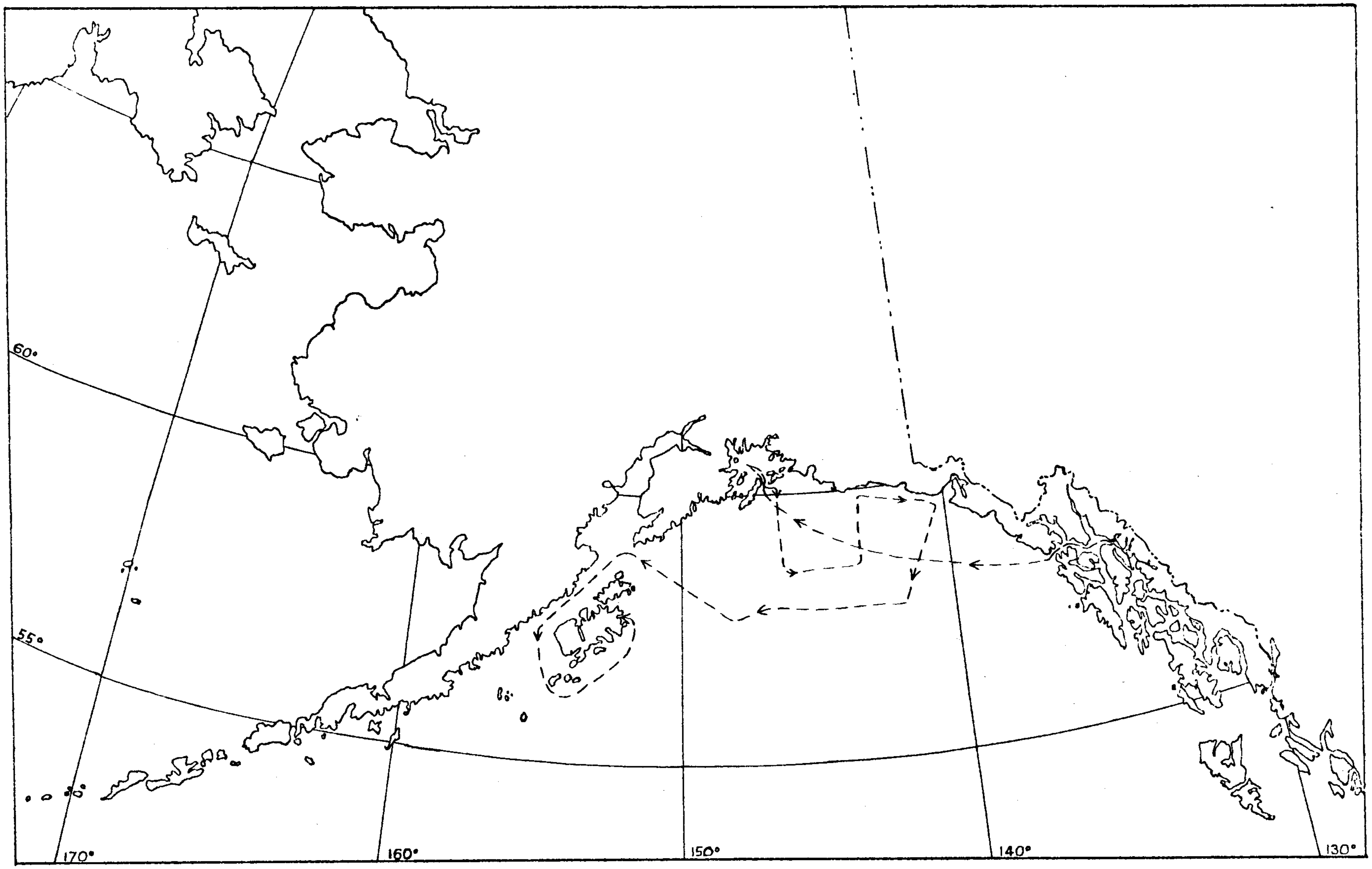


Fig. 29. Trackline of Surveyor, October 29 - November 8, 1975.

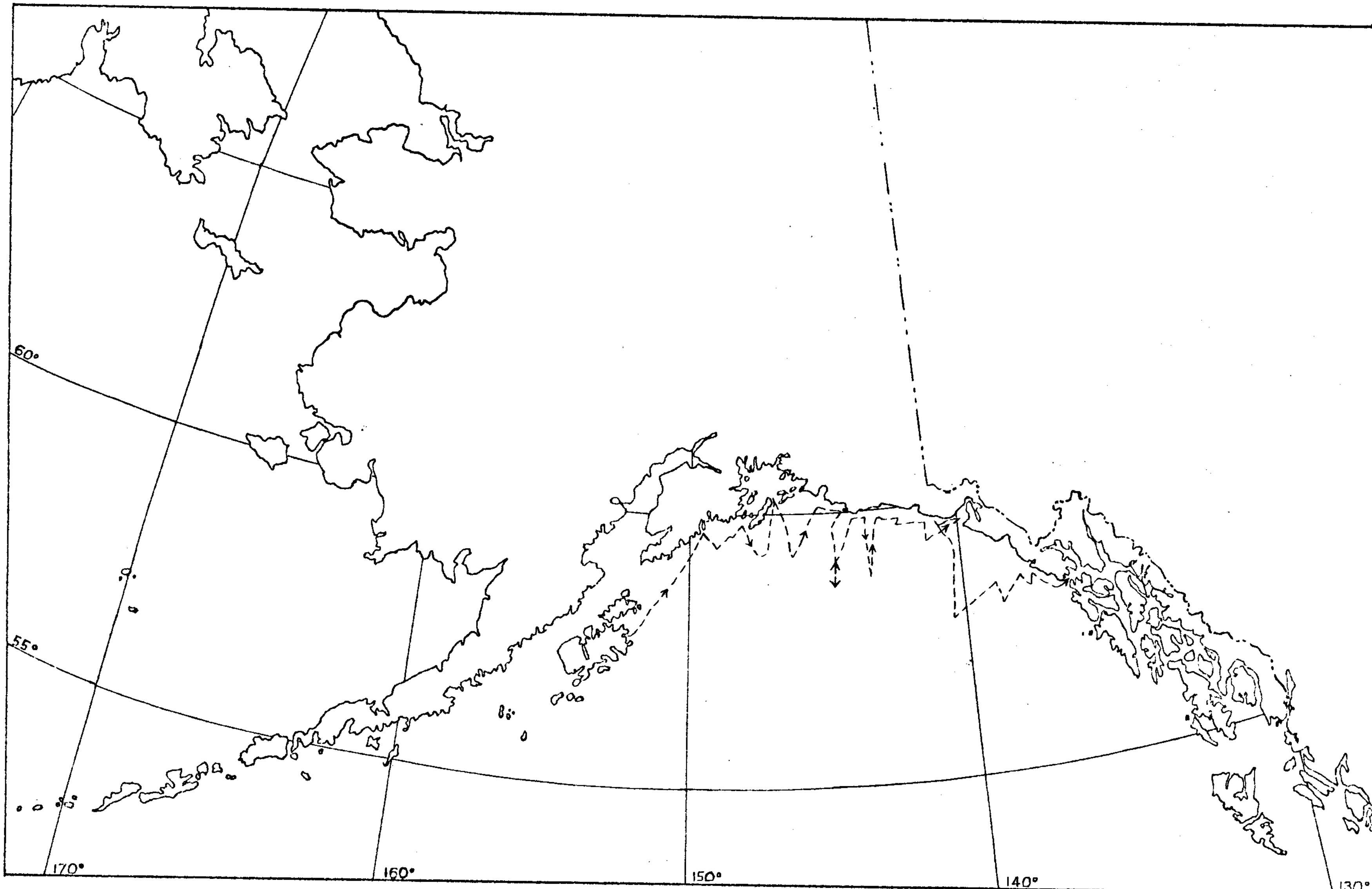


Fig. 30. Trackline of Discoverer, April 13-29, 1976.

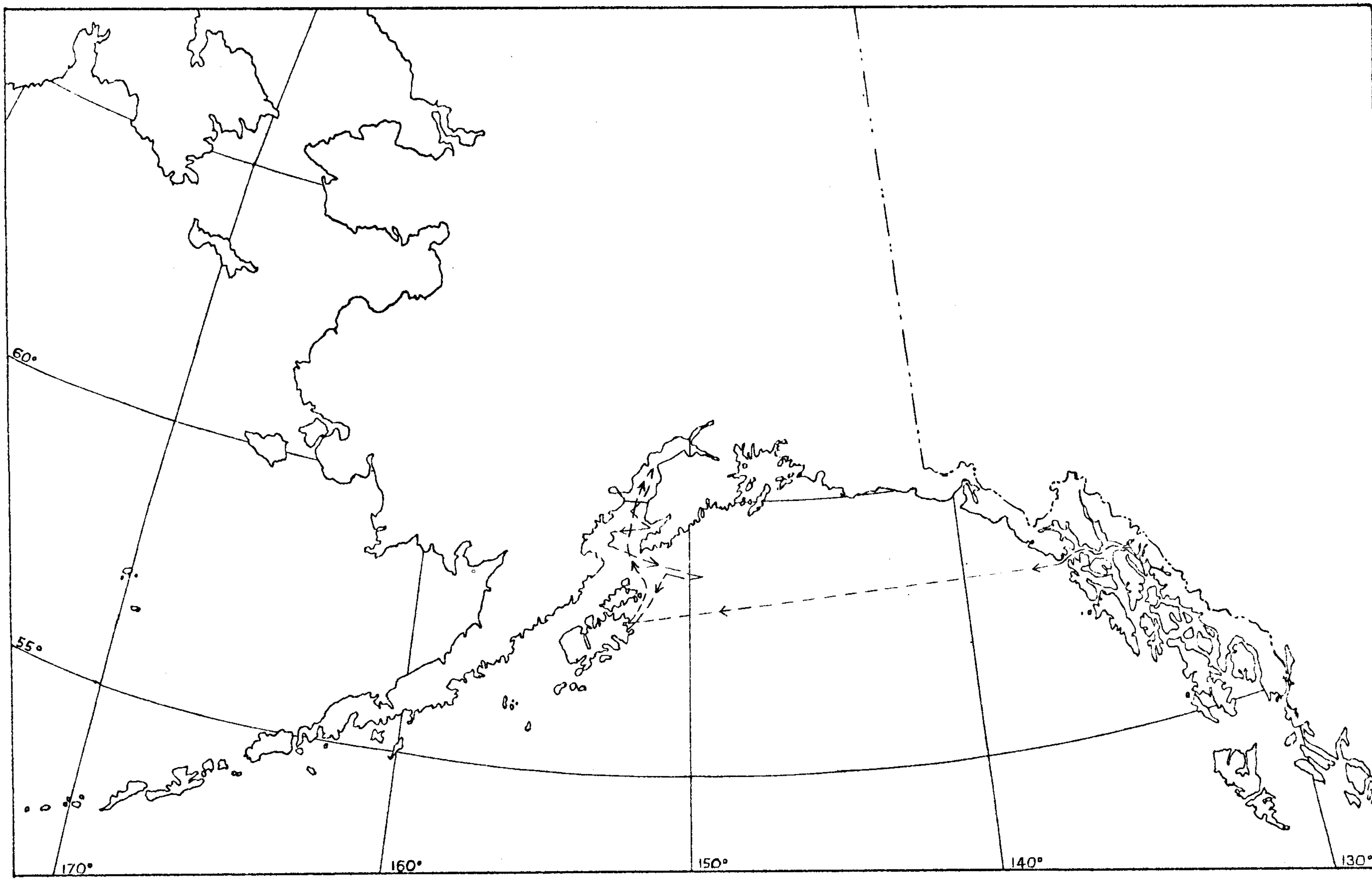


Fig. 31. Trackline of Discoverer, May 4-11, 1976.

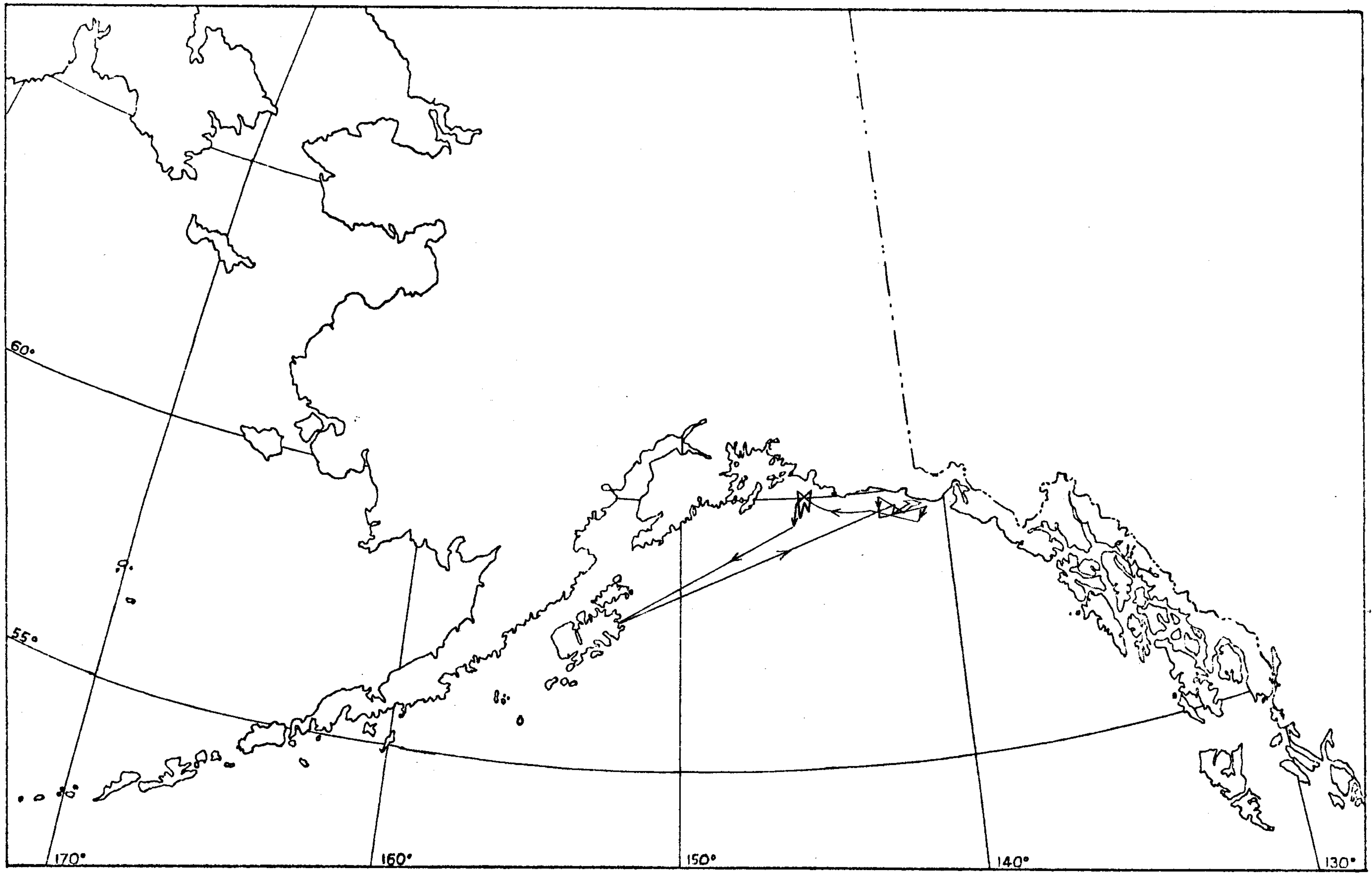


Fig. 32. Trackline of Discoverer, May 10-19, 1976.

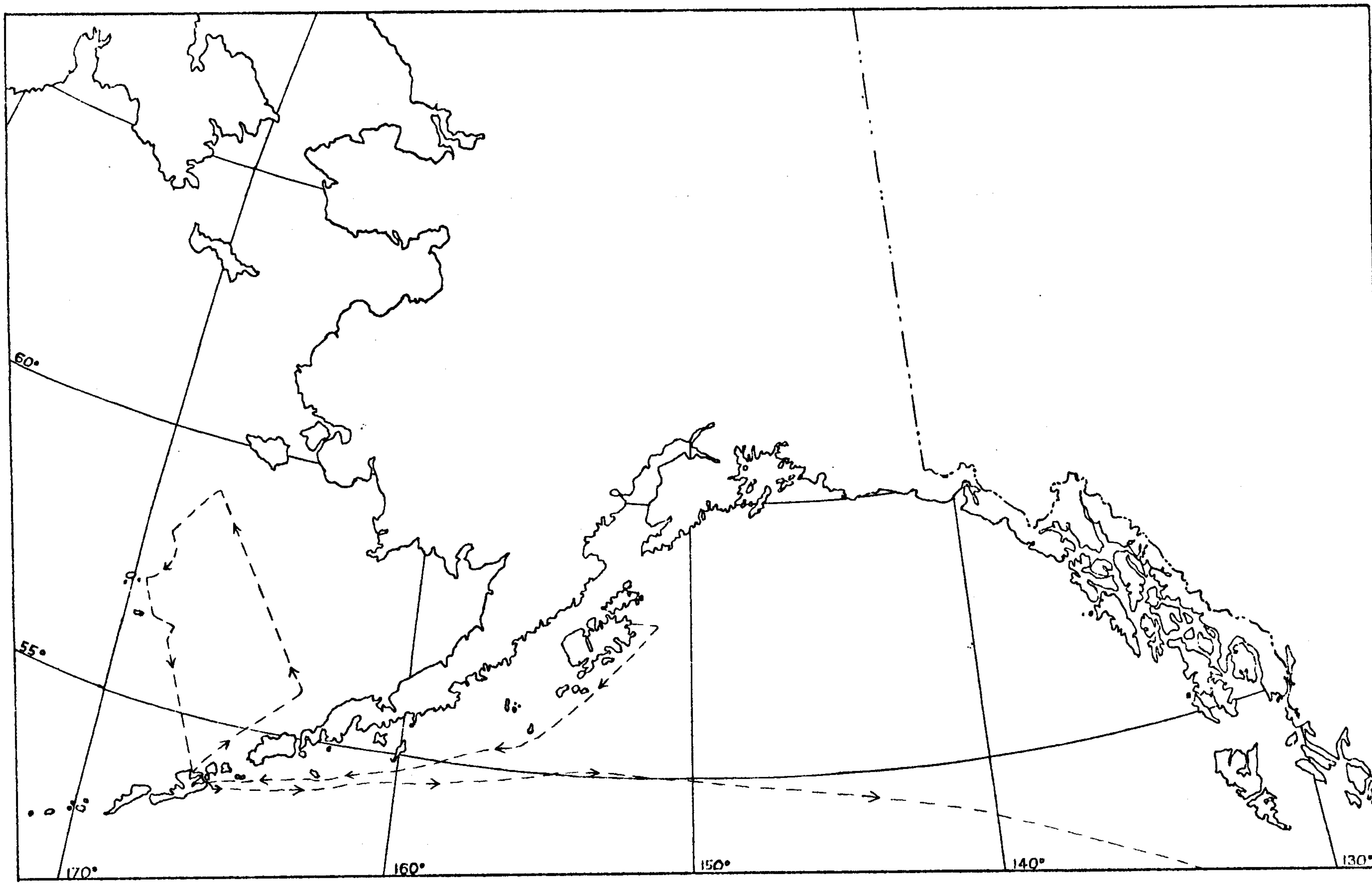


Fig. 33. Trackline of Miller Freeman, June 6-23, 1976.

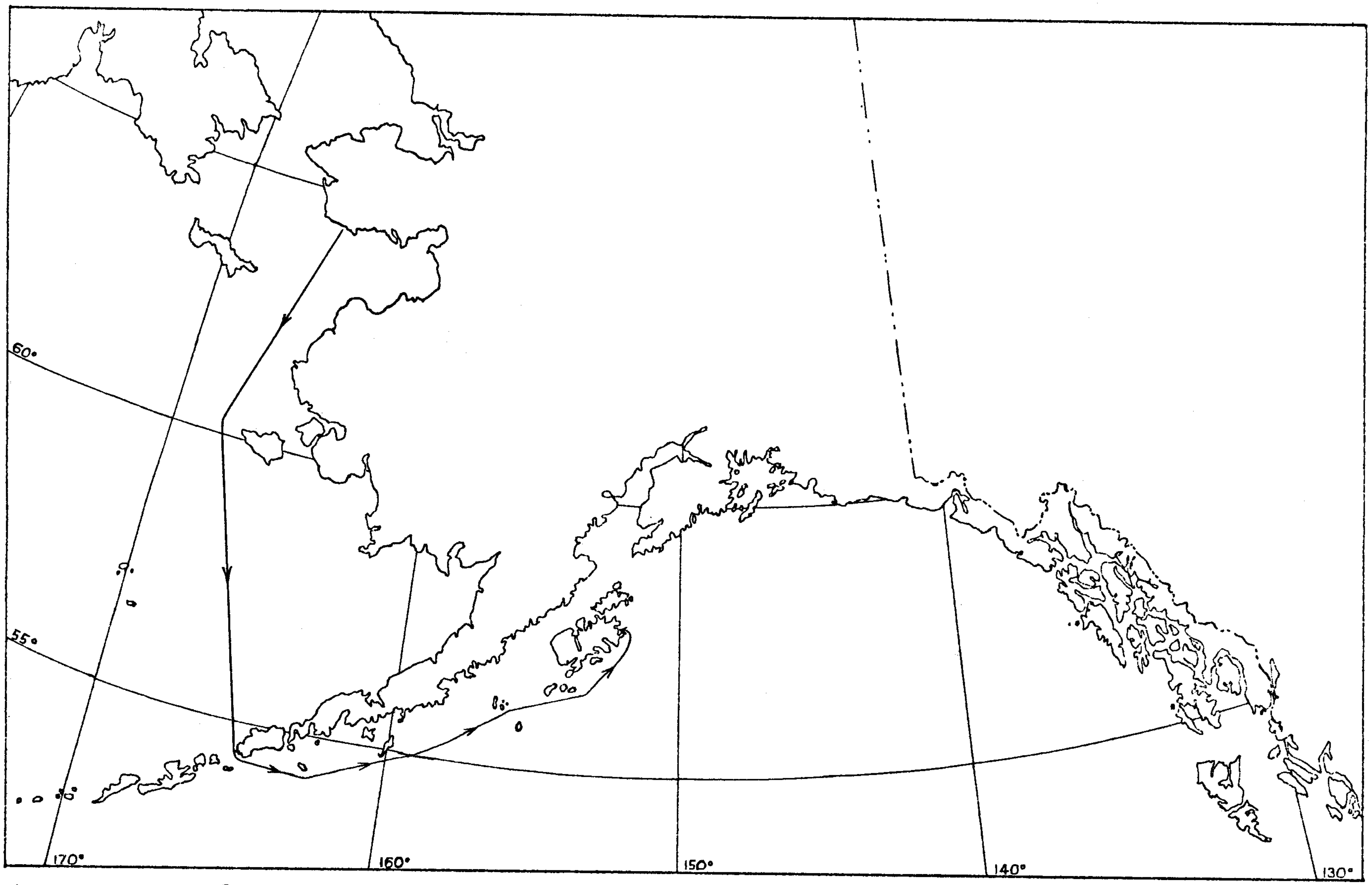


Fig. 34. Trackline of Surveyor, August 16-20, 1976.

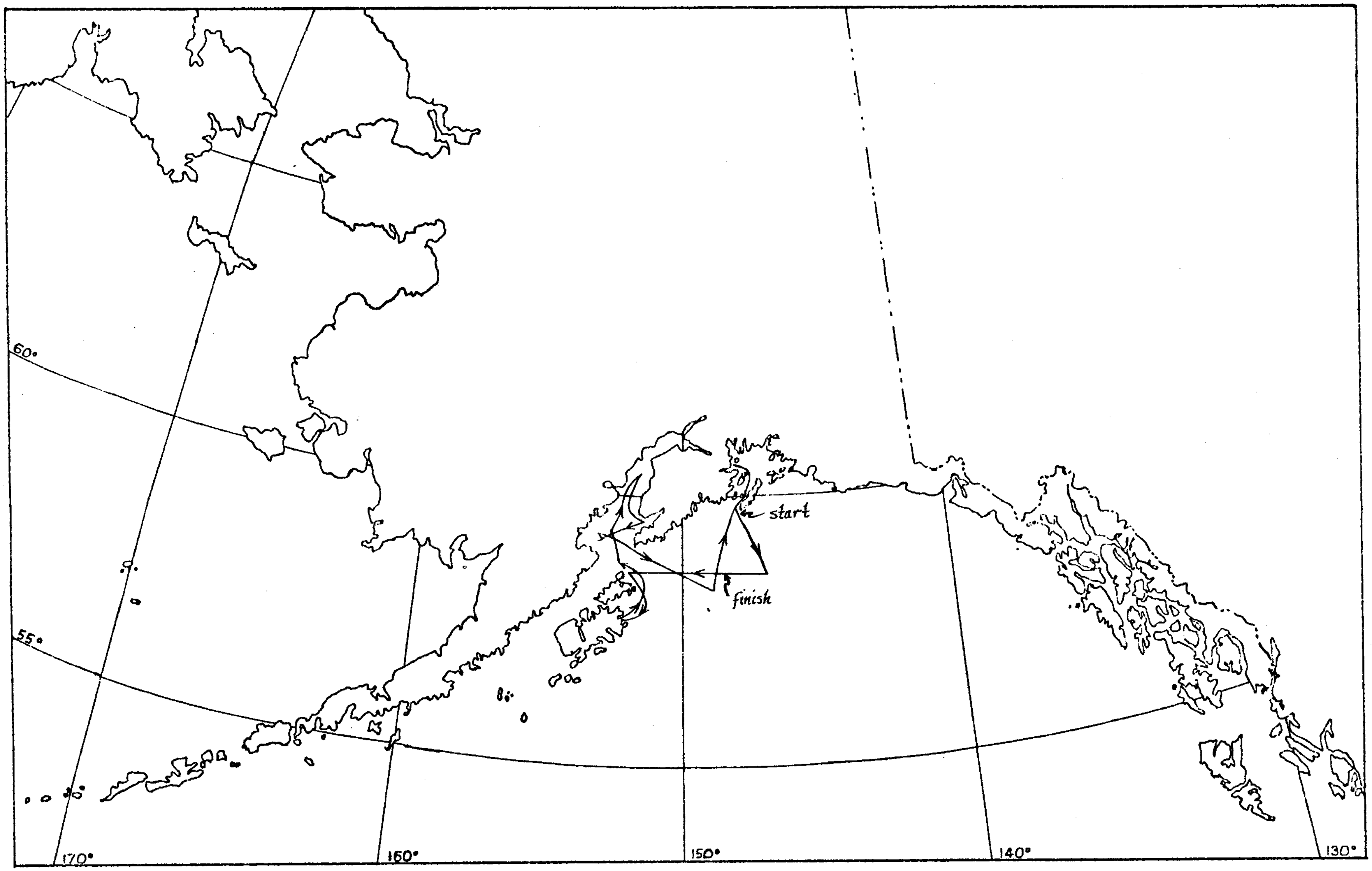


Fig. 35. Trackline of Surveyor, August 24 - September 3, 1976.

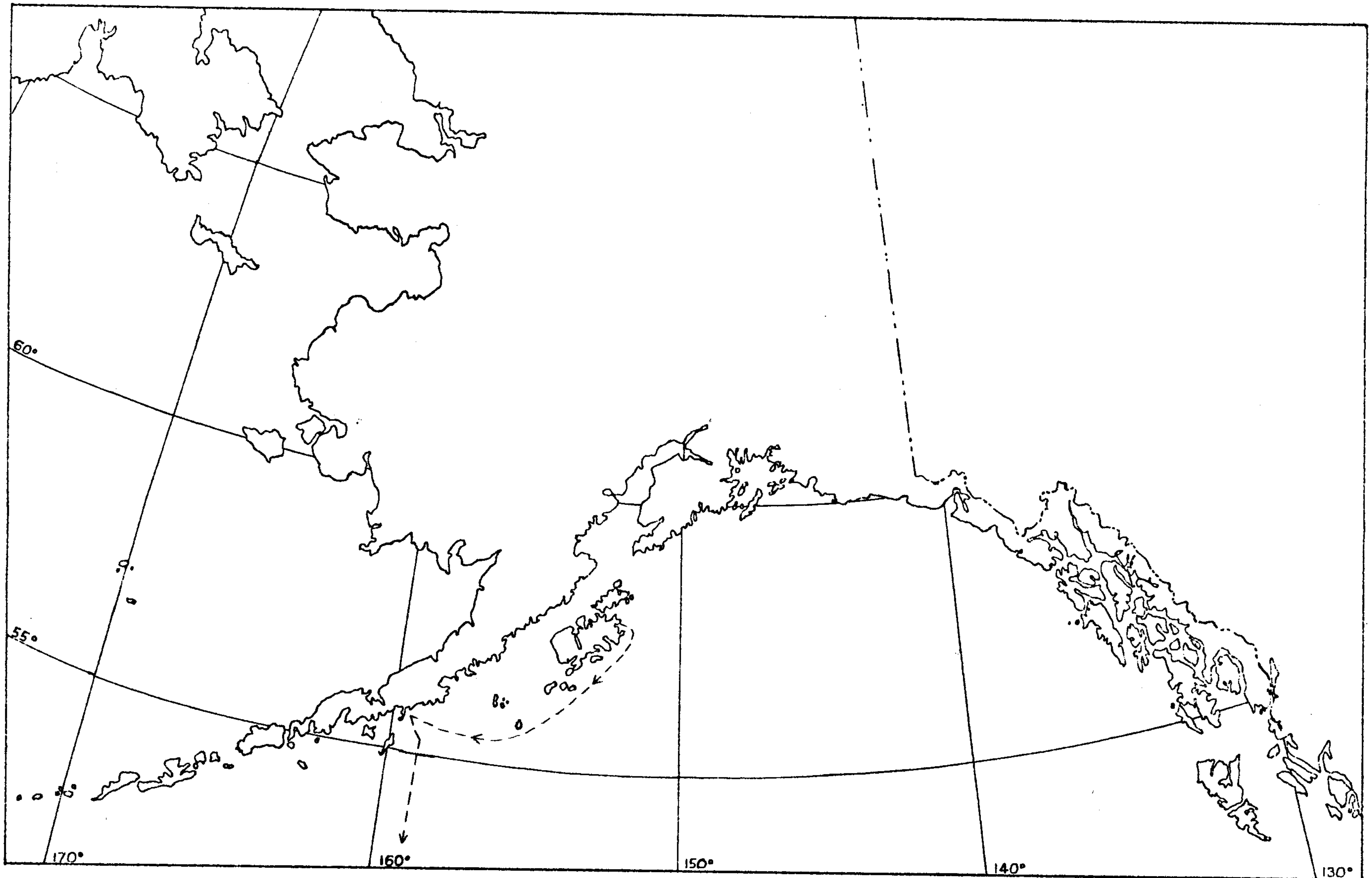


Fig. 36. Trackline of Moana Wave, October 22 - November 6, 1976.

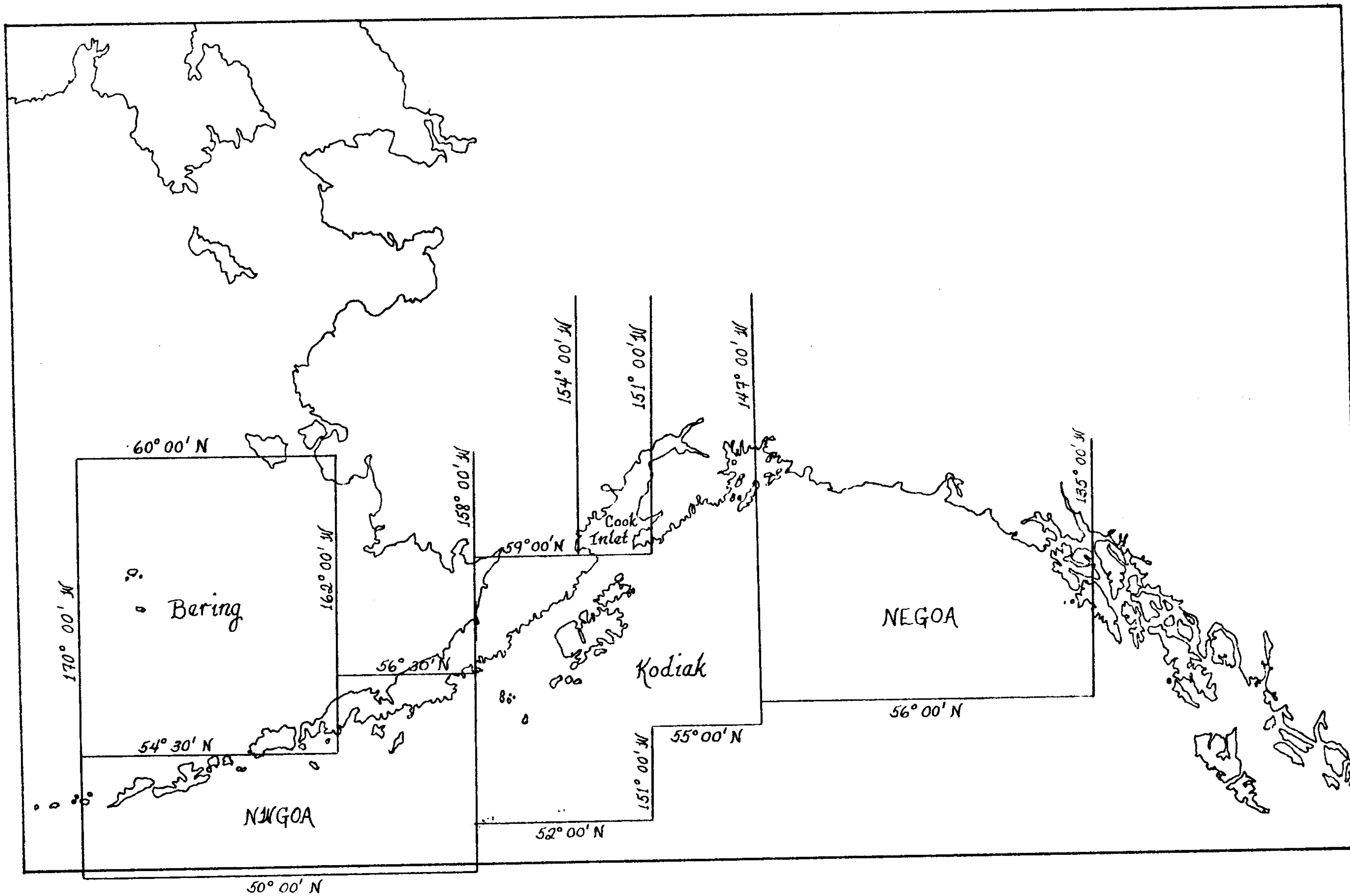


Figure 37. Areas of the Gulf of Alaska/Bering Sea used to summarize marine bird transect census results.

Table 5

Sampling Effort

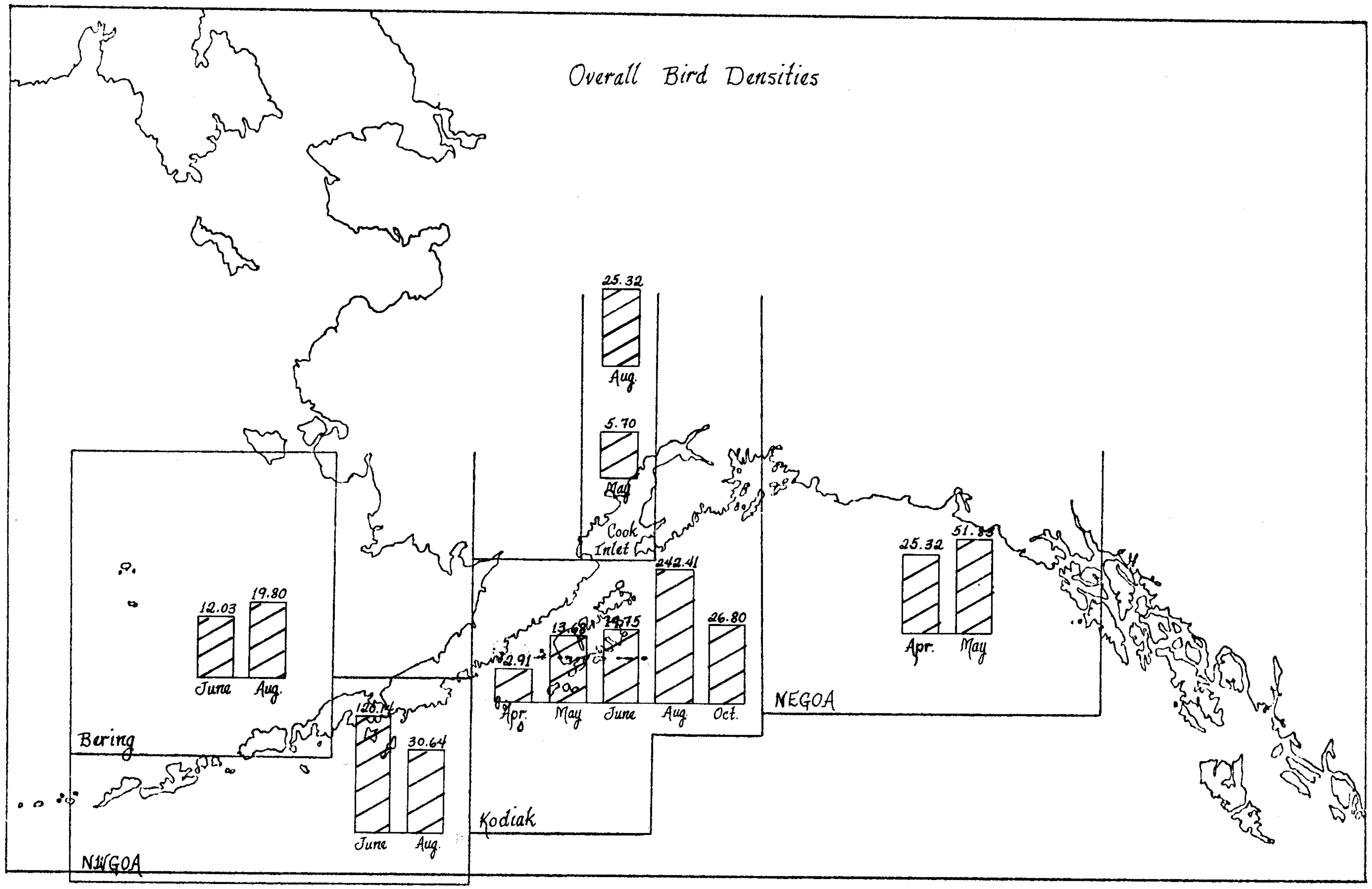
Time - Area Blocks		Cruises	Inclusive Dates of Data Collection	Transects Number	Transects Minutes	Transects Kilometers
NEGOA	April	1614	4/17 - 4/30	49	915	302
	May	1615	5/4 - 5/5	4	120	56
		1616	5/12 - 5/20	22	675	263
				26	795	319
Kodiak	April	1614	4/15 - 4/16	9	150	55
	May	1615	5/8	2	30	14
		1616	5/11, 5/20	6	180	72
				8	210	86
	June	2614	6/19	5	150	66
	Aug. - Sept.	0622	8/24, 8/29 - 9/2	23	900	314
	October	3607	10/23 - 10/25	14	405	110
Cook	May	1615	5/6 - 5/8	6	105	35
	August	0622	8/25 - 8/28	13	375	127
NWGOA	June	2614	6/10 - 6/11, 6/18	8	240	102
	August	0621	8/18	5	150	50
Bering	June	2614	6/12 - 6/17	12	345	144
	August	0621	8/16 - 8/17	8	240	86

Table 6

Overall Bird Densities

Time-Area Blocks		Sample Size (n)	Overall Density (ind./km²)
NEGOA	April	49	25.32
	May	26	51.83
Kodiak	April	9	2.91
	May	8	13.68
	June	5	19.75
	Aug.-Sept.	23	242.41
	October	14	26.80
Cook	May	6	5.70
	August	13	25.32
NWGOA	June	8	120.14
	August	5	30.64
Bering	June	12	12.03
	August	8	19.80

Fig. 38



Densities of marine birds (all species combined), derived from transect censuses. Values are averages from all censuses conducted in an area during the indicated time period. Histograms indicate the relative abundances, as measured by the logarithms of the actual average densities. All following figures (30-39) employ this display.

birds, the overall density will be underestimated, and if another has mostly large conspicuous birds, its overall density may be overestimated, at least relative to other areas. Because of statistical problems relating to the averaging technique, we did not calculate confidence intervals for these overal densities.

Several patterns are apparent in the data. In the NEGOA, where our sample sizes are most adequate, bird densities doubled from April to May. The higher May density resulted from an influx of migrants, including phalaropes, ducks, and shearwaters.

Kodiak had very low spring densities but much higher late summer and fall densities. These reflect concentrations of shearwaters. The extremely high August-September values are due to immense shearwater concentrations in the region from Portlock Bank to Perenosa Bay, of Afognak.

The relatively low densities recorded for the Eastern Bering Sea reflect the fact that most transects were far from land. The increase in Bering Sea densities between June and August can largely be explained by the influx of shearwaters during that period. Tremendous numbers of Short-tailed Shearwaters feed in mid and late summer in the Eastern Bering Sea, but we missed these concentrations in our sample of transects.

The high densities recorded for the NEGOA result from concentrations of Short-tailed Shearwaters and Tufted Puffins.

Cook Inlet has generally lower densities than the other regions, and most of the birds that do occur are found at the lower end of the Inlet, and out toward the Barren Islands.

Species Densities

Species densities have been calculated for the dominant species in the five study areas (NEGOA, Kodiak, Cook Inlet, NWGOA and Southeastern Bering Sea) shown in figure 37. Densities have been calculated individually for Northern Fulmars, Fork-tailed Petrels, Black-legged Kittiwakes, Arctic Terns, Horned Puffins, and Tufted Puffins. The other dominant species (shearwaters, large gulls and murres) occur as pairs of species which are sometimes difficult to distinguish at sea. We have therefore reported overall densities for the groups, and also the ratio of the component species identified within the groups. This gives us larger group sample sizes to work with, since many distant birds were identified only to group.

The confidence intervals we report are typically rather wide. Three major factors prevent us from determining more precise confidence intervals. Bird distributions are seldom uniform over the areas analyzed. Many species are much more common over the continental shelf than beyond the shelf margin, or vice versa. The pooling of data from both domains adds heterogeneity. In some areas our coverage was insufficient, as only occasional short cruises were available. Additionally, for the shearwaters the heterogeneity of the birds' distribution caused the confidence intervals to remain large. Shearwaters frequently are gathered into extremely large concentrations, so even with extensive coverage of an area, there will be great variation in density per transect, because some transects will, and many will not, encounter large flocks.

A number of conservative biases remain in our analyses, so it is unlikely that many of the actual species densities are below the reported average densities. In most cases we expect the actual density to lie between the reported density and the upper limit of the confidence interval.

Fulmar (Table 7, Figure 39)

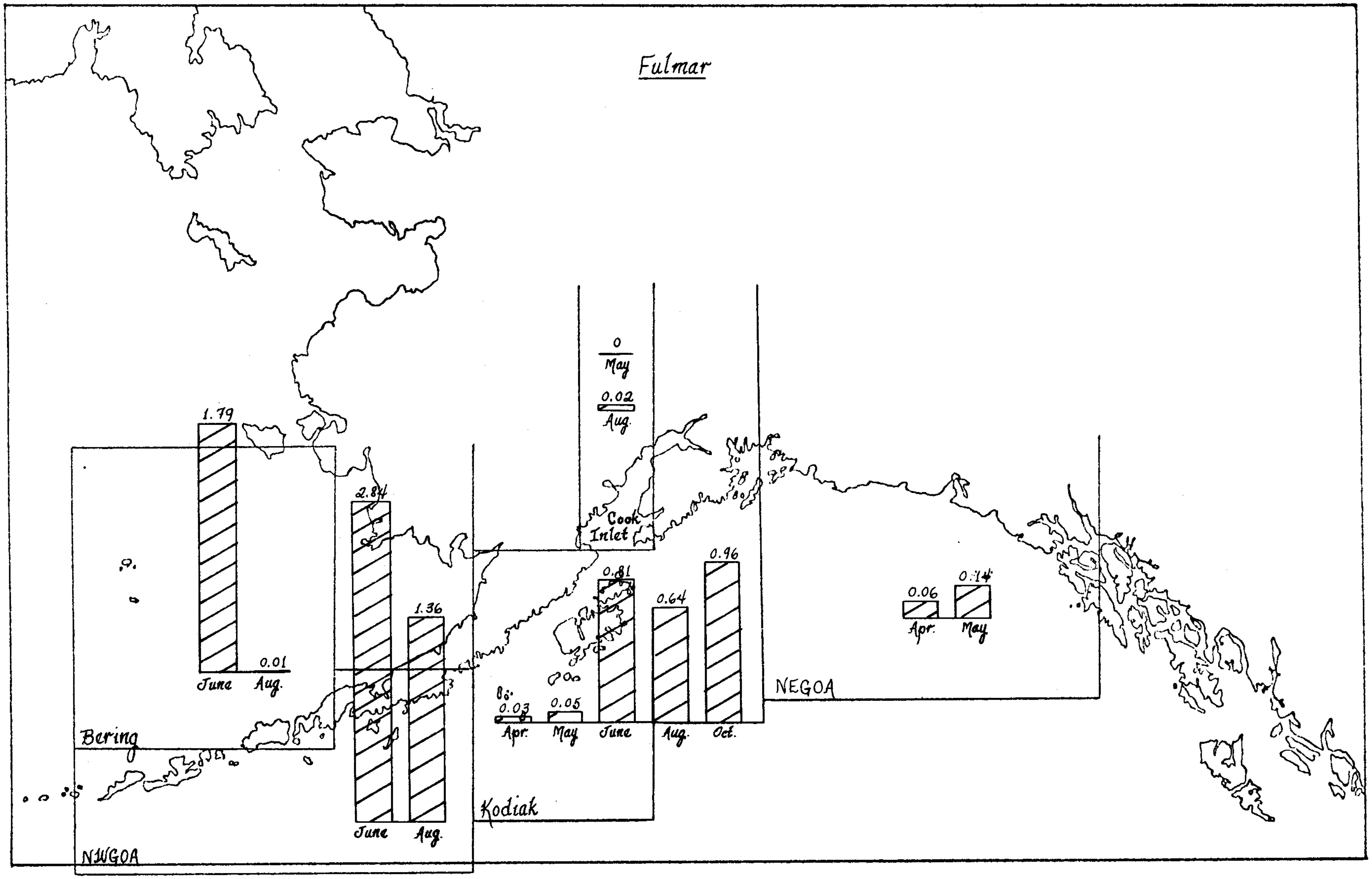
Fulmars were found throughout the areas covered in all months sampled (except Cook Inlet, in May). They occur close inshore and out to well beyond

Table 7

Fulmar

Time-Area Blocks		Sample Size (n)	Density (ind./km²) Mean	± 95% C.I.
NEGOA	April	49	0.06	0.11
	May	26	0.14	0.10
Kodiak	April	9	0.03	0.06
	May	8	0.05	0.08
	June	5	0.81	0.26
	Aug.-Sept.	23	0.64	0.50
	October	14	0.96	0.54
Cook	May	6	0	0
	August	13	0.02	0.03
NWGOA	June	8	2.84	2.74
	August	5	1.36	0.89
Bering	June	12	1.79	1.74
	August	8	0.01	0.02

Fig. 39


Fulmar
0
May
0.02
Aug.
Cook
Inlet
1.79
0.01
June
Aug.
Bering
2.84
1.36
June
Aug.
NWGOA
Kodiak
0.03
0.05
0.81
0.64
0.96
Apr.
May
June
Aug.
Oct.
NEGOA
0.06
0.14
Apr.
May

the continental shelf edge. Densities were higher in the Western Gulf and the Bering Sea than in the NEGOA. Previous observations indicate that along the shelf break between the Pribilofs and the Aleutians may be an area of much higher densities than we have recorded farther east. Fulmars do not appear to range very far into Cook Inlet, but our data base for that area is small.

Shearwaters (Table 8 Figure 40)

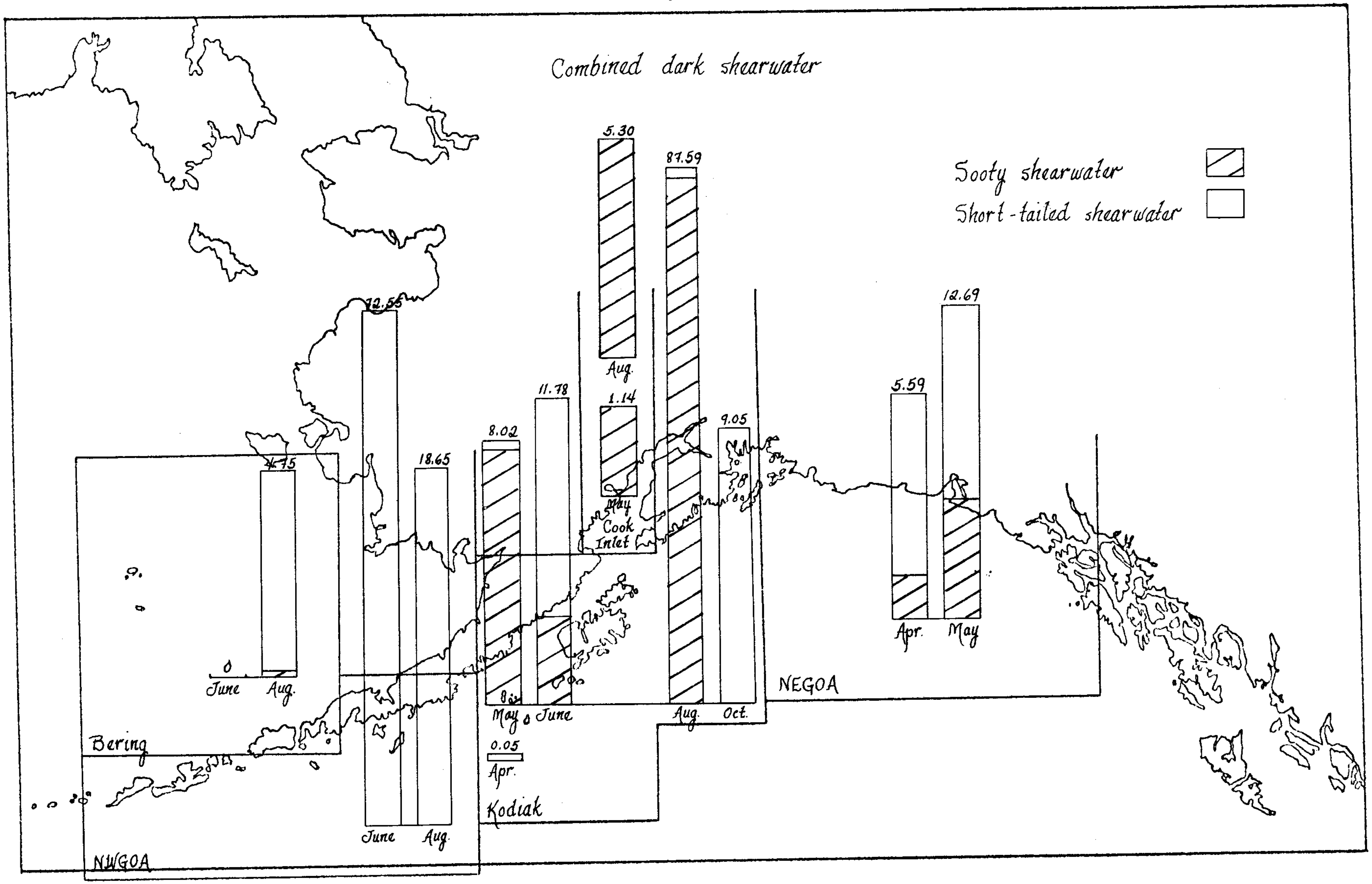
The two common Alaskan shearwater species show complex distributional relationships. Both breed in the Australasian area and migrate into the North Pacific in their non-breeding season, April to October. Short-tailed shearwaters arrived in the NEGOA before Sooty Shearwaters, and predominated in April and May. However, Sooty Shearwaters were abundant in the Kodiak area by mid-May (the densities recorded in Table 8 show an overwhelming preponderance of Sooty Shearwaters in the Kodiak area in May, but observations made off the south coast of Kodiak while studying feeding flocks indicate that Short-tailed Shearwaters were more common in that area). In June, Short-tails were more common than Sooties off Kodiak and were abundant in the NWGOA, especially just south of the eastern Aleutians. However, no shearwaters were seen in the Bering Sea in June. In August, they were common in the eastern Bering Sea, with Short-tails predominating. In August and early September Sooty Shearwaters were abundant again around Kodiak and common in lower Cook Inlet. At the same time, Short-tailed Shearwaters were extremely abundant in the eastern Aleutian passes (shorebased observations made while studying feeding flocks). In October the area from Kodiak to the Semidi Islands was populated largely by Short-tailed Shearwaters, and they were observed migrating south into the Central Pacific.

Table 8

Combined dark shearwater

Time-Area Blocks		Sample Size (n)	Mean	Density (ind./km²) ± 95% C.I.	Density Ratios (SS/STS)
NEGOA	April	49	5.59	4.46	0.256
	May	26	12.69	11.14	0.641
Kodiak	April	9	0.05	0.08	All STS
	May	8	8.02	9.59	47.964
	June	5	11.78	32.26	0.392
	Aug.-Sept.	23	87.59	105.92	53.068
	October	14	9.05	9.16	0.0019
Cook	May	6	1.14	2.91	All SS/STS
	August	13	5.30	7.15	All SS
NWGOA	June	8	72.55	145.59	0.0015
	August	5	18.65	32.18	0.00097
Bering	June	12	0	0	
	August	8	4.75	3.59	0.0211

Fig. 40


Combined dark shearwater
Sooty shearwater
Short-tailed shearwater
5.30
Aug.
1.14
May
Cook Inlet
87.59
Aug.
9.05
Oct.
11.78
June
8.02
May
0.05
Apr.
Kodiak
18.65
June
Aug.
0
June
Aug.
Bering
NWGOA
NEGOA
5.59
Apr.
12.69
May

Fork-tailed Petrel (Table 9, Figure 41)

Fork-tailed Petrels were absent from the NEGOA in April but were observed moving north into the region in early May. They are normally more prevalent around the shelf break and off the shelf than on the shelf, but they do occur into nearshore areas. They do not seem to extend far into Cook Inlet. The high density recorded for the NWGOA is a reflection of the preponderance of offshore and offshelf transects in that sample.

Jaegers (Table 10, Figure 42)

We have combined the three Jaeger species for analysis because they are sometimes difficult to separate at sea, and because the sample size for each of the species is too small for individual analysis. They were rare in the NEGOA in April, and their northward migration into the area appeared to be concentrated in early May. This corresponds closely with the northward migration of Arctic Terns, one of their principal prey species. They were widely distributed at sea throughout the months May to September. In most areas the birds seen at sea in June through August were probably largely nonbreeders, as most Jaegers nest inland, but the area of southwestern Kodiak and the Trinity, Semidi, and Shumagin Islands is inhabited by a population of Parasitic Jaegers which appears to feed at sea throughout the breeding season.

The October-November Moana Wave cruise appeared to coincide with the southward migration of the Jaegers, and they were seen throughout the cruise, even into Hawaiian waters.

Large Gulls (Table 11, Figure 43)

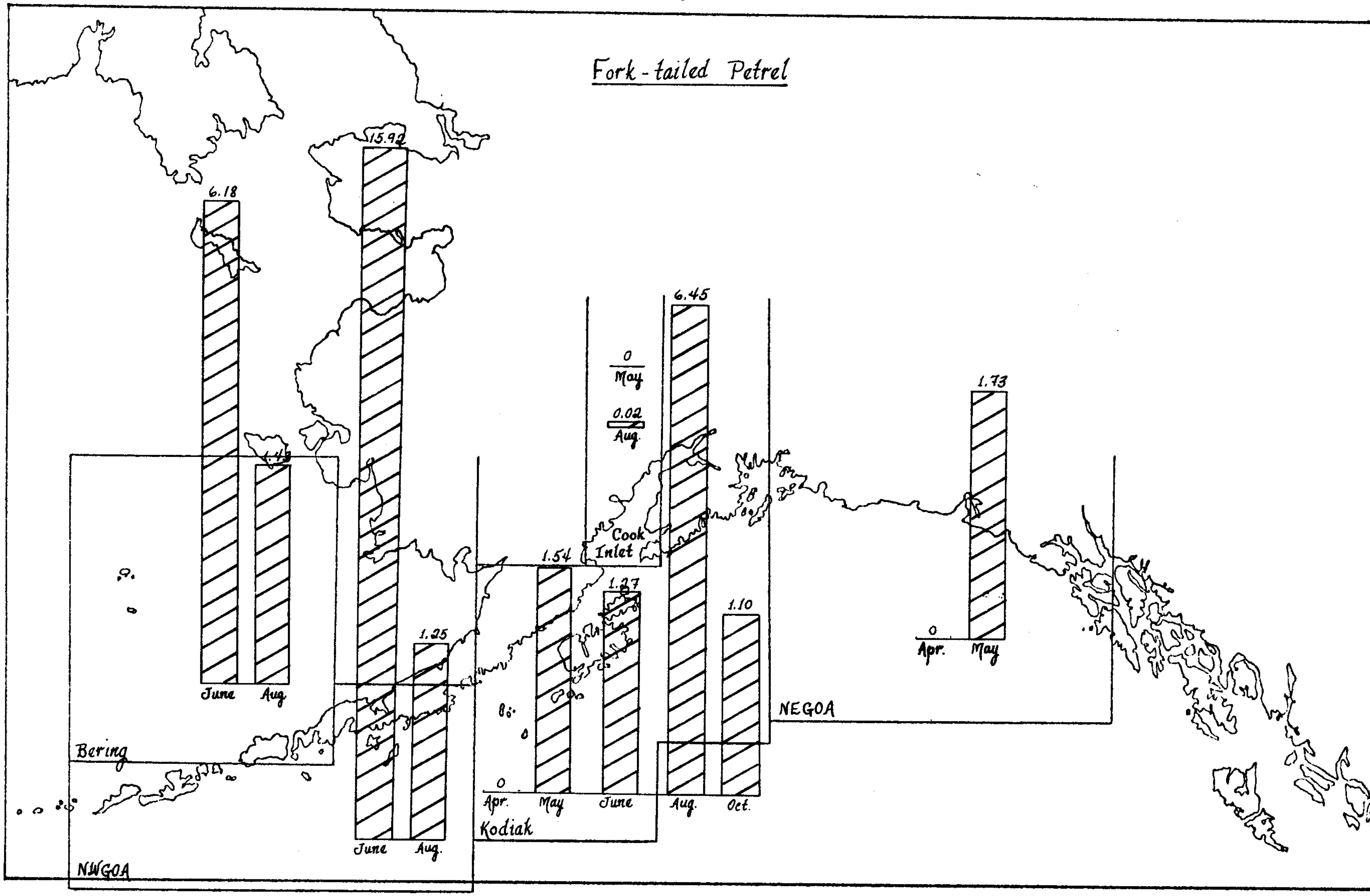
Glaucous-winged Gulls are common breeding birds on the islands and headlands throughout the areas studied. In addition large numbers of Herring Gulls and much smaller numbers of Thayer's Gulls and Glaucous Gulls winter at

Table 9

Fork-tailed Petrel

Time-Area Blocks		Sample Size (n)	Density (ind./km²) Mean	± 95% C.I.
NEGOA	April	49	0	0
	May	26	1.73	1.37
Kodiak	April	9	0	0
	May	8	1.54	1.30
	June	5	1.27	1.89
	Aug.-Sept.	23	6.45	4.43
	October	14	1.10	0.95
Cook	May	6	0	0
	August	13	0.02	0.04
NWGOA	June	8	15.92	24.65
	August	5	1.25	1.41
Bering	June	12	6.18	8.90
	August	8	1.43	2.23

Fig. 41



Fork-tailed Petrel
6.18
15.92
June
Aug
1.25
June
Aug.
Bering
NWGOA
0
May
0.02
Aug.
Cook
Inlet
6.45
1.54
1.27
1.10
0
Apr.
May
June
Aug.
Oct.
Kodiak
1.73
0
Apr.
May
NEGOA

Table 10

Combined jaeger

Time-Area Blocks		Sample Size (n)	Density (ind./km²) Mean	± 95% C.I.
NEGOA	April	49	0.004	0.007
	May	26	0.05	0.04
Kodiak	April	9	0	0
	May	8	0	0
	June	5	0.05	0.07
	Aug.-Sept.	23	0.14	0.10
	October	14	0.10	0.11
Cook	May	6	0	0
	August	13	0.01	0.02
NWGOA	June	8	0	0
	August	5	0.12	0.12
Bering	June	12	0.01	0.02
	August	8	0.07	0.08

Fig. 42

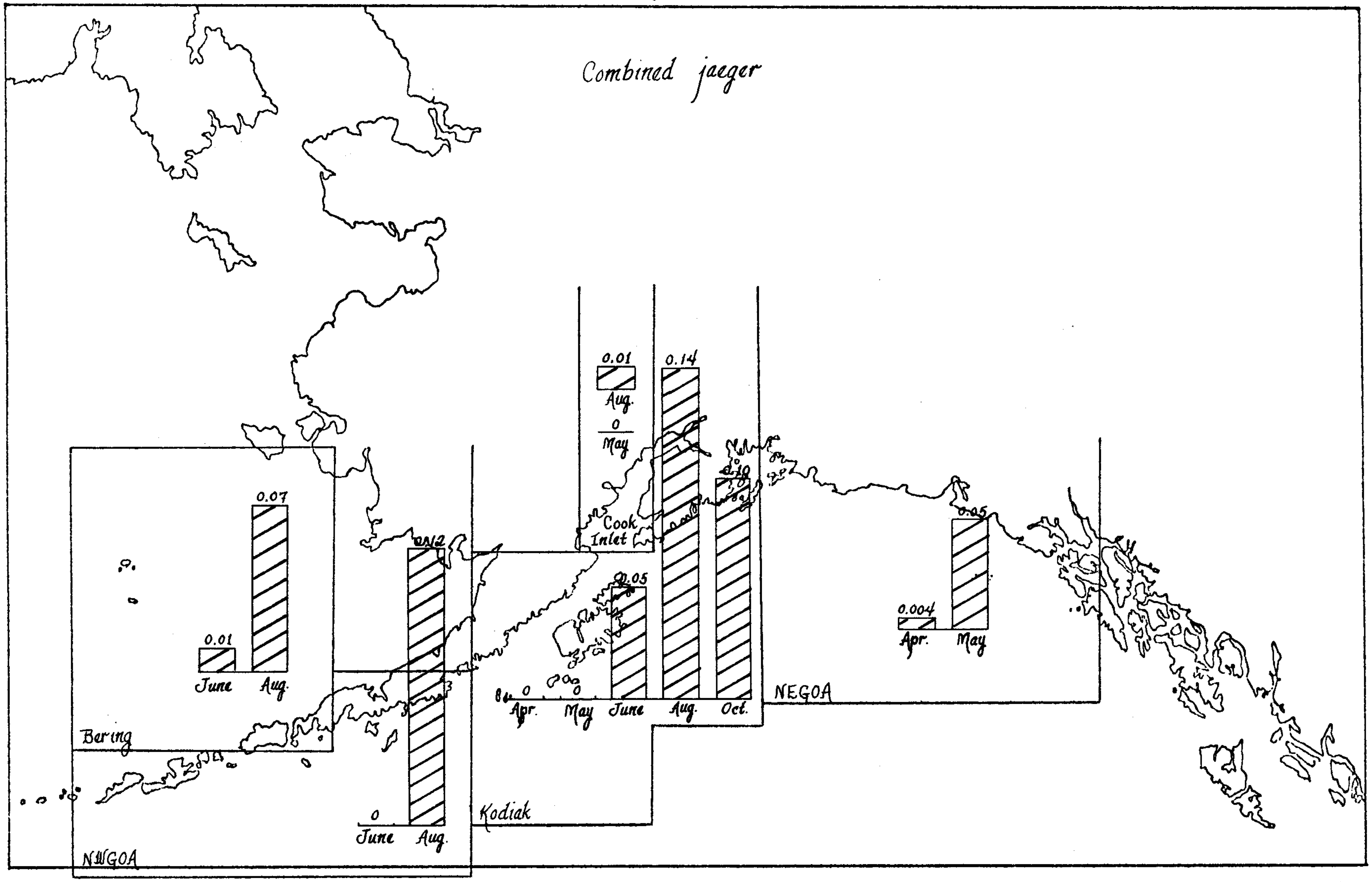
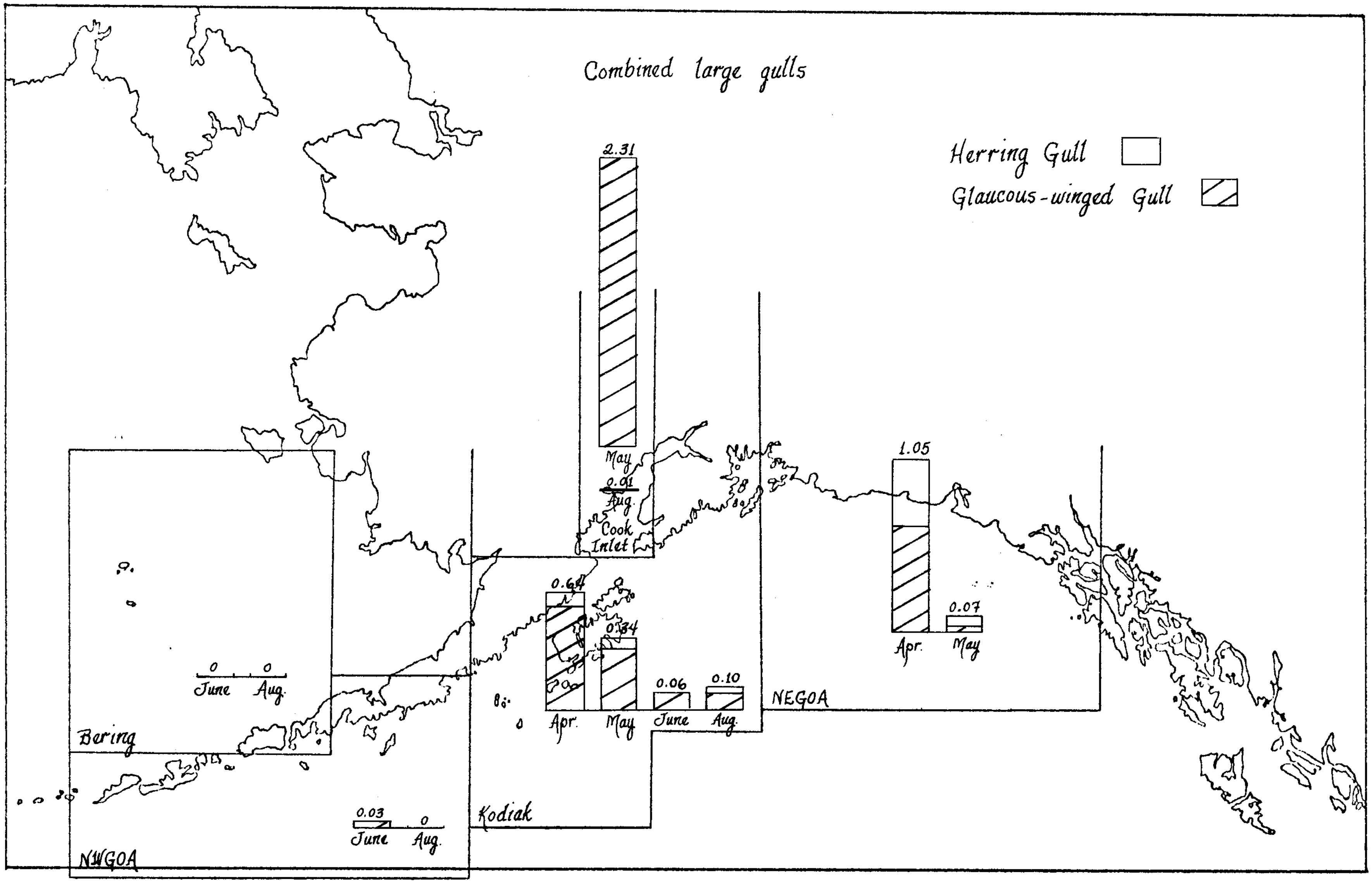

Combined jaeger
0.07
0.01
June
Aug.
Bering
0.12
0
June
Aug.
NWGOA
0.01
Aug.
0
May
Cook Inlet
0.14
0.10
0.05
0
0
Apr.
May
June
Aug.
Oct.
Kodiak
0.05
0.004
Apr.
May
NEGOA

Table 11

Combined large gulls

Time-Area Blocks		Sample Size (n)	Density (ind./km²) Mean	± 95% C.I.	Density Ratios (GWG/HG)
NEGOA	April	49	1.05	0.69	1.57
	May	26	0.07	0.05	0.96
Kodiak	April	9	0.64	0.29	8.977
	May	8	0.34	0.42	6.624
	June	5	0.06	0.07	All GWG
	Aug.-Sept.	23	0.10	0.09	4.807
	October	14	not calculated	not calculated	
Cook	May	6	2.31	5.38	All GWG
	August	13	0.01	0.02	All GWG
NWGOA	June	8	0.03	0.04	All GWG
	August	5	0	0	
Bering	June	12	0	0	
	August	8	0	0	

Fig. 43



Combined large gulls
Herring Gull
Glaucous-winged Gull
2.31
May
0.01
Aug.
Cook Inlet
1.05
Apr.
May
0.07
0.64
0.34
0.06
0.10
Apr.
May
June
Aug.
NEGOA
0
0
June
Aug.
Bering
0.03
0
June
Aug.
Kodiak
NWGOA

sea in the area, especially in the NEGOA. They range far out to sea in the nonbreeding season, but in summer only Glaucous-winged Gulls remain at sea in any numbers, and they are concentrated near shore. In April and May both Herring and Glaucous-winged Gulls are present at similar densities in the NEGOA. Herring gulls are rare around Kodiak at all seasons, and essentially absent farther west. The very low densities of gulls recorded for the NWGOA and Bering Seas in June reflect the fact that almost all transects taken in these areas were far offshore.

Black-legged Kittiwake (Table 12 Figure 44)

Kittiwakes were recorded in all areas and all months (none were recorded on transects in April, Kodiak area, or NWGOA, August, in small numbers of transects but on both cruises they were observed between transects). They were typically more common closer to shore in summer, but were regularly observed far offshore as well. Highest densities were recorded in the Kodiak area. Numbers were consistantly higher in the summer months than in April, which is consistant with observations that a large portion of the population migrates southward to winter.

Arctic Tern (Table 13, Figure 45)

Arctic Terns began migrating north through the Gulf of Alaska around 30 April, although we did have one early observation on 20 April. Our data show clearly a wave of migrants in May (most of these birds were in fact observed flying north) and another wave in August-September. Arctic Terns were not seen at sea in June, during their breeding season, but again were found at sea in August-September, before or during their fall migration. Thus a bimodal seasonal pattern is defined, with use of the ocean occurring primarily during migration. (During summer Arctic Terns can be regularly observed in inshore areas and bays, where we cannot take transects.)

Table 12

Black-legged Kittiwake

Time-Area Blocks		Sample Size (n)	Density (ind./km²) Mean	± 95% C.I.
NEGOA	April	49	0.37	0.27
	May	26	0.85	0.58
Kodiak	April	9	0	0
	May	8	10.66	13.30
	June	5	0.27	0.56
	Aug.-Sept.	23	1.21	0.67
	October	14	not calculated	not calculated
Cook	May	6	0.41	0.71
	August	13	2.62	1.44
NWGOA	June	8	0.05	0.07
	August	5	0	0
Bering	June	12	0.66	0.59
	August	8	0.42	0.38

Fig. 44

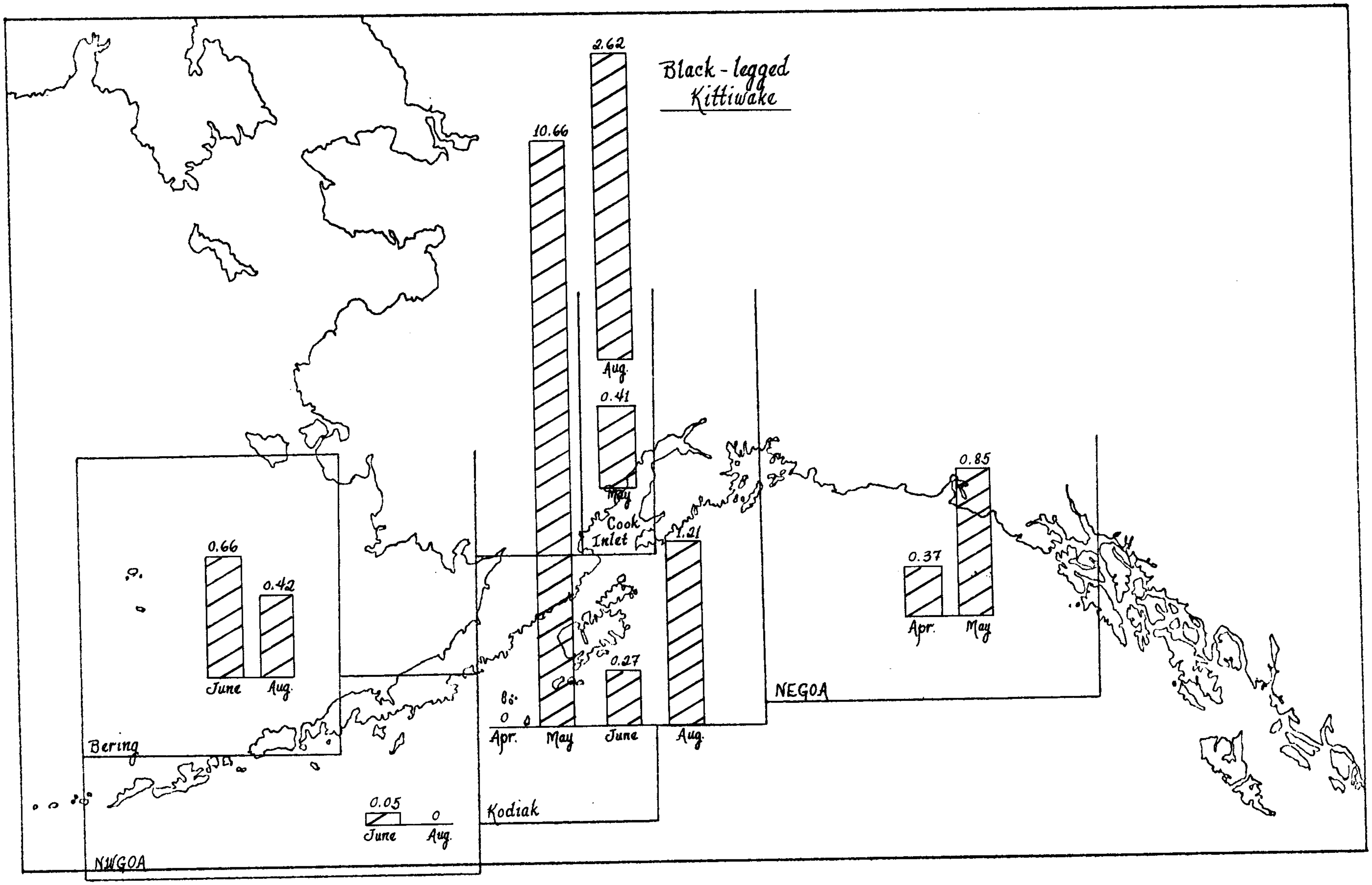
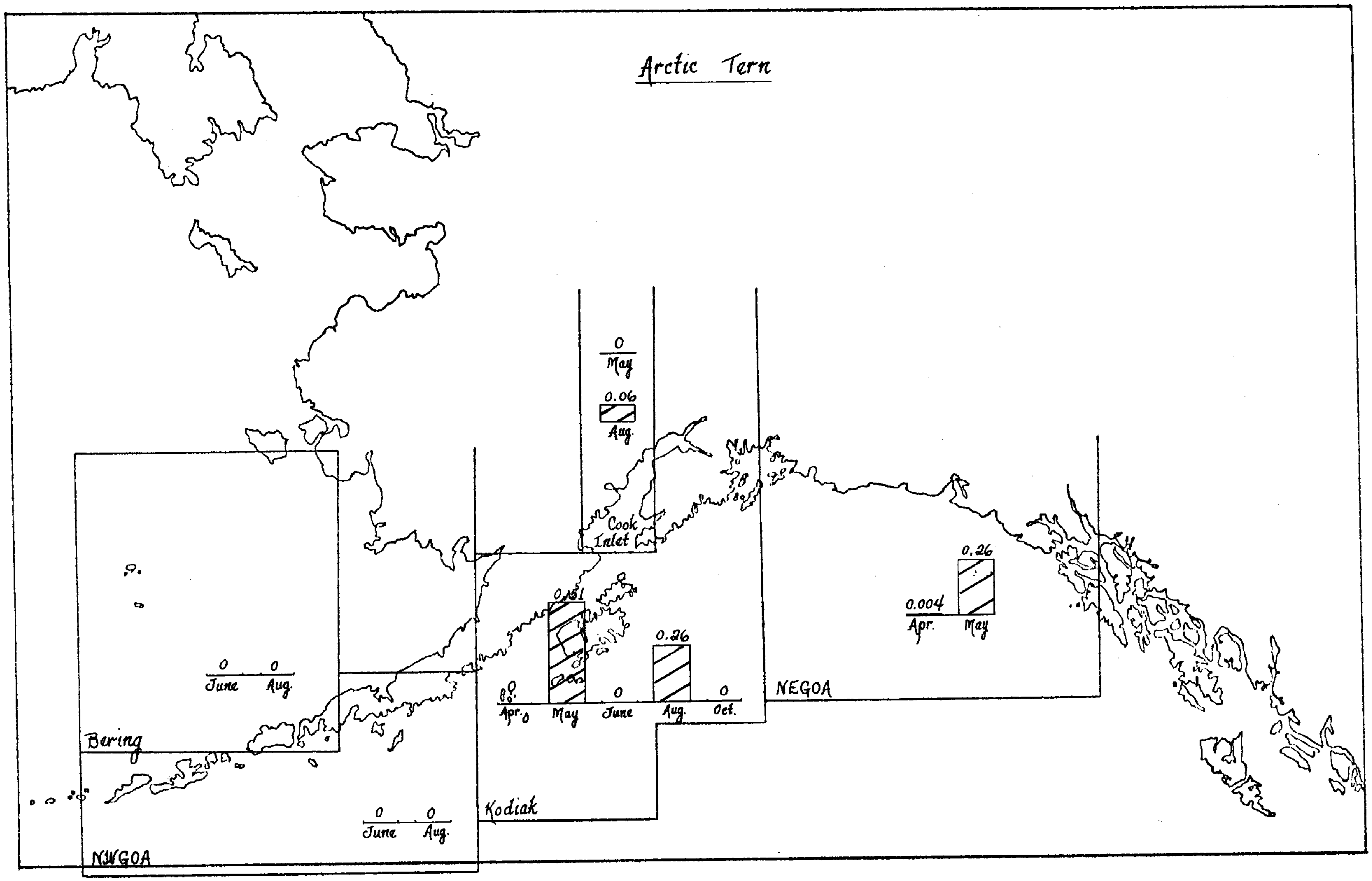

Black-legged Kittiwake
2.62
10.66
Aug.
0.41
May
Cook Inlet
1.21
0.85
0.37
Apr.
May
0.66
0.42
June
Aug.
0.27
0
Apr.
May
June
Aug.
NEGOA
Bering
Kodiak
0.05
0
June
Aug.
NWGOA

Table 13

Arctic Tern

Time - Area Blocks		Sample Size (n)	Density (ind./km²) Mean	± 95% C.I.
NEGOA	April	49	0.004	0.01
	May	26	0.26	0.19
Kodiak	April	9	0	0
	May	8	0.51	1.22
	June	5	0	0
	Aug.- Sept.	23	0.26	0.51
	October	14	0	0
Cook	May	6	0	0
	August	13	0.06	0.06
NWGOA	June	8	0	0
	August	5	0	0
Bering	June	12	0	0
	August	8	0	0

Fig. 45


Arctic Tern
0
May
0.06
Aug.
Cook Inlet
0.31
May
Apr.
0
June
0.26
Aug.
0
Oct.
NEGOA
0.004
Apr.
0.26
May
0
June
0
Aug.
Bering
Kodiak
0
June
0
Aug.
NWGOA

<u>Murres</u> (Table 14, Figure 46)

Common and thick-billed Murres were combined for this analysis because they have very similar detection functions and because they are sometimes difficult to separate at sea. Common Murres were present in all areas in all months sampled. We did not find Thick-billed Murres east of Kodiak, although they are known to breed in small numbers on Afognak Island and Middleton Island. Thick-billed Murres were found regularly, but at lower densities than Common Murres, in the NWGOA. This situation is reversed in the Bering Sea, where Thick-billed Murres may outnumber Common Murres by as much as four to one. The overall density of Murres was found to be higher in the NWGOA and Bering Sea than to the east.

<u>Horned Puffin</u> (Table 15, Figure 47)

Horned Puffins were very rare in the NEGOA and Kodiak areas until late May. They have the latest arrival dates of any of the Alaskan breeding seabirds. The density of 0.01 recorded for the NEGOA in April is based upon a few birds seen in one transect off Yakutat. Breeding Horned Puffins often concentrate closer inshore than our vessels operated, so our summer densities are underestimates of the actual population size. The highest densities recorded were for October, in the Kodiak area. Many of these birds were far offshore, apparently dispersing to their wintering areas in the North Pacific. Observations by USFWS personnel and ourselves in the OCSEAP program demonstrate that Horned Puffins do not winter in any numbers nearshore in Alaskan waters, but disperse well out into the central North Pacific (on the Moana Wave cruise, October 1976, we observed them south to 45°N 158°W). Until now, the wintering area of the Horned Puffin has been a matter of dispute.

Table 14

Combined murre

Time-Area Blocks		Sample Size (n)	Density (ind./km²) Mean	± 95% C.I.	Density Ratios (CM/TBM)
NEGOA	April	49	0.20	0.19	All CM
	May	26	0.06	0.05	All CM
Kodiak	April	9	0.39	0.53	All CM
	May	8	0.44	0.45	All CM
	June	5	0.02	0.06	All CM
	Aug.-Sept.	23	0.20	0.18	All CM
	October	14	0.04	0.04	All CM
Cook	May	6	0.32	0.39	All CM
	August	13	0.72	0.80	All CM
NWGOA	June	8	0.66	0.50	1.415
	August	5	0.03	0.09	All CM
Bering	June	12	5.61	2.19	0.229
	August	8	1.10	2.36	0.649

Fig. 46

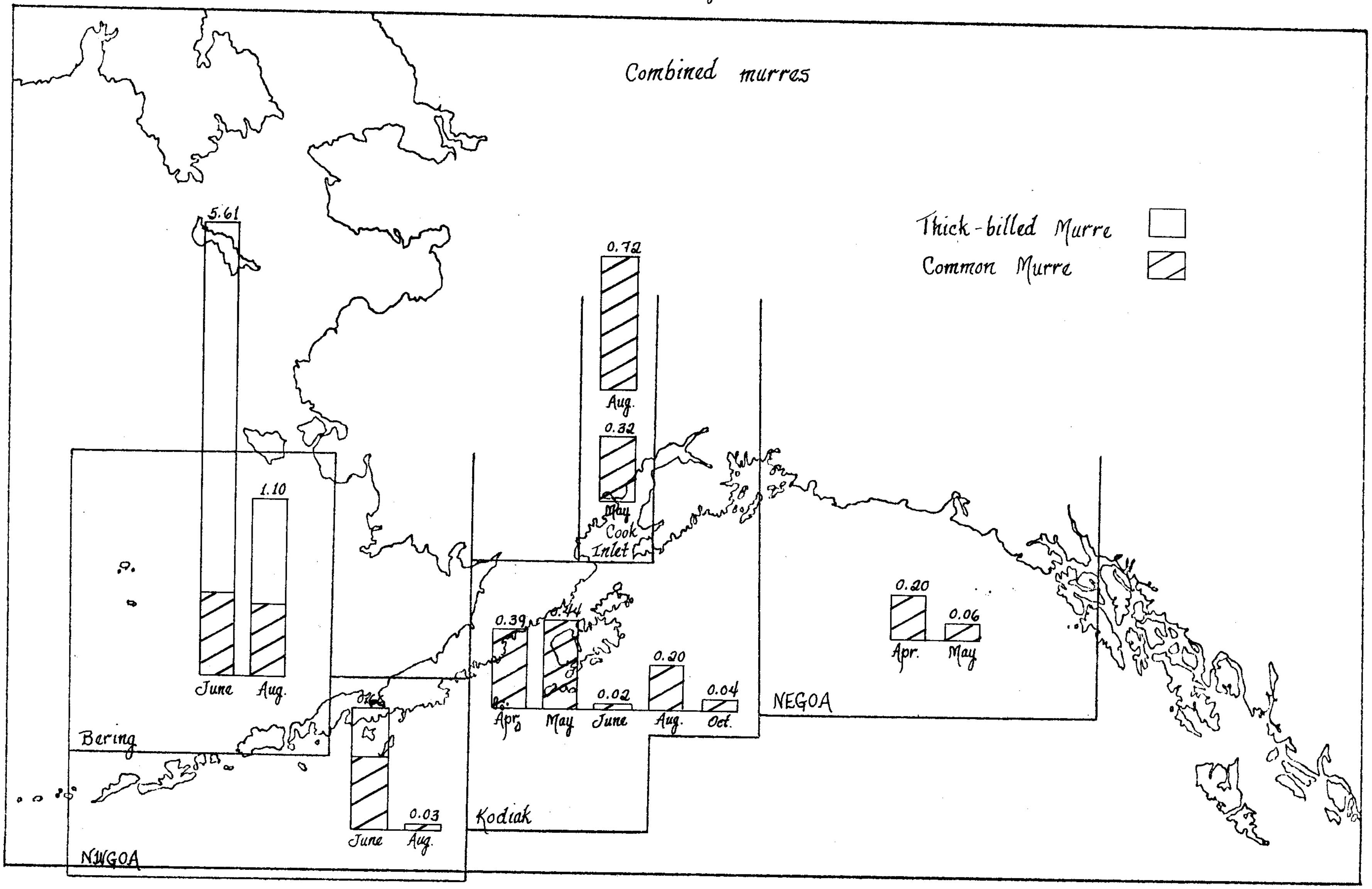
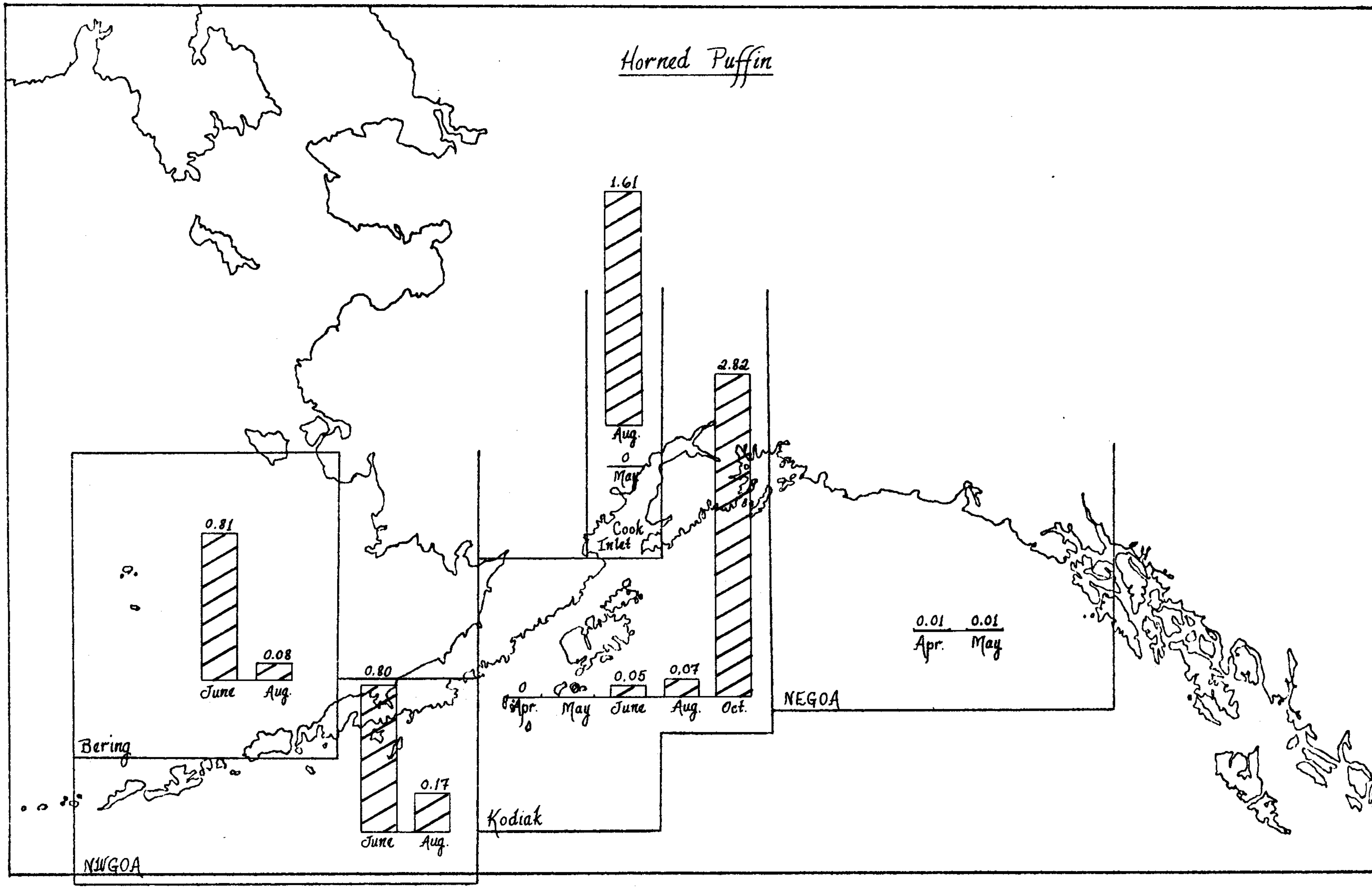

Combined murres
Thick-billed Murre
Common Murre
5.61
1.10
June
Aug.
Bering
0.72
Aug.
0.32
May
Cook Inlet
0.39
0.44
0.02
0.20
0.04
Apr.
May
June
Aug.
Oct.
Kodiak
0.03
June
Aug.
NWGOA
0.20
0.06
Apr.
May
NEGOA

Table 15

Horned Puffin

Time-Area Blocks		Sample Size (n)	Density (ind./km²) Mean	± 95% C.I.
NEGOA	April	49	0.01	0.02
	May	26	0.01	0.02
Kodiak	April	9	0	0
	May	8	0	0
	June	5	0.05	0.08
	Aug.-Sept.	23	0.07	0.06
	October	14	2.82	3.24
Cook	May	6	0	0
	August	13	1.61	2.01
NWGOA	June	8	0.80	1.12
	August	5	0.17	0.46
Bering	June	12	0.81	1.40
	August	8	0.08	0.12

Fig. 47


Horned Puffin
1.61
Aug.
0
May
Cook Inlet
2.82
0.81
0.08
June
Aug.
Bering
0.80
0.17
June
Aug.
NWGOA
0
Apr.
May
0.05
June
0.07
Aug.
Oct.
Kodiak
NEGOA
0.01
Apr.
0.01
May

Tufted Puffin (Table 16, Figure 48)

Tufted Puffins were present in the study areas in all months sampled. Densities are higher in nearshore waters in summer, and off the continental shelf in spring and fall. In the Gulf of Alaska, densities of Tufted Puffins increase greatly from east to west. Although the data presented in table 12 do not show it, this trend continues into the eastern Aleutians, where Tufted Puffin densities are much higher than anywhere else in the Gulf of Alaska. Some Tufted Puffins, like Horned Puffins, disperse far south into the central North Pacific in fall.

Relationship of Densities to the Environment

The information presented here is based on one set of 10 consecutive transects for which we have reliable data on depth, temperature and salinity. The transects were taken on 1 September 1976 in the far eastern portion of the Kodiak region (arrows in figure35 show beginning and ending positions for the series of transects). The densities for the six most abundant species (Northern Fulmar, Sooty Shearwater, Short-tailed Shearwater, Fork-tailed Petrel, Black-legged Kittiwake, and Tufted Puffin) were analyzed in relation to depth, temperature, and salinity. Principal Component Analysis (PCA) was used to elucidate the patterns within each data set (i.e., species data and environmental data), and Canonical Correlation Analysis (CCA) was used to pick out the patterns in one, best accounted for by the other.

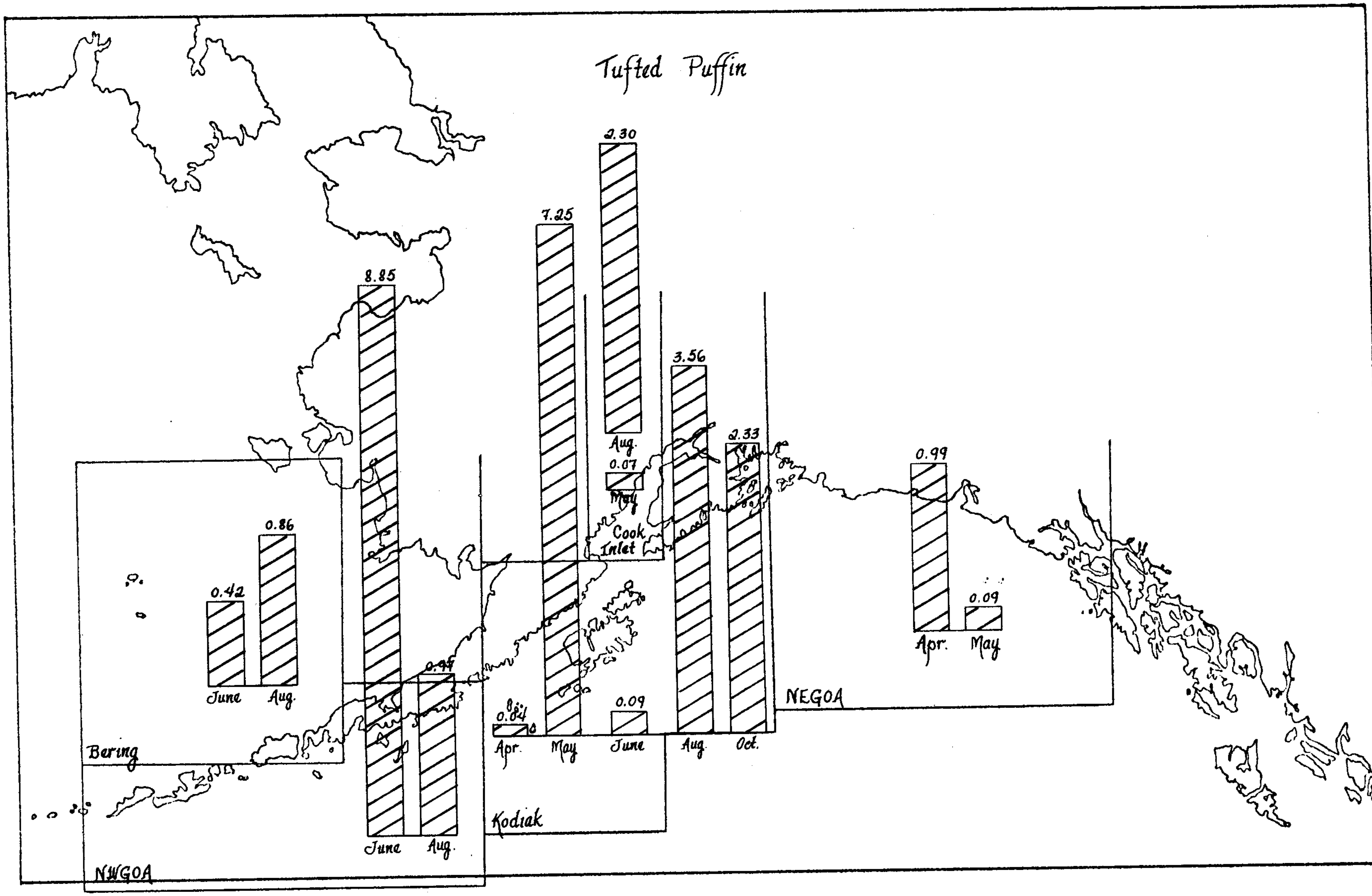
The first principal component of the environmental data (PC1(ENV)) accounted for 87% of the variation in the data.[1] PC1 primarily represented a gradient from relatively shallow cold and low salinity areas to deeper, colder and more saline areas. The correlations between these variables was quite high (0.65 to 0.85). The remaining components did not provide any patterns of interest.

Table 16

Tufted Puffin

Time-Area Blocks		Sample Size (n)	Density (ind./km²) Mean	± 95% C.I.
NEGOA	April	49	0.99	0.78
	May	26	0.09	0.09
Kodiak	April	9	0.04	0.10
	May	8	7.25	4.18
	June	5	0.09	0.18
	Aug.-Sept.	23	3.56	2.35
	October	14	2.33	1.32
Cook	May	6	0.07	0.19
	August	13	2.30	3.48
NWGOA	June	8	8.85	4.63
	August	5	0.97	0.59
Bering	June	12	0.42	0.45
	August	8	0.86	1.24

Fig. 48



Tufted Puffin
8.85
7.25
2.30
Aug.
0.07
May
Cook Inlet
3.56
2.33
0.99
0.09
Apr.
May
0.42
0.86
June
Aug.
Bering
0.94
June
Aug.
NWGOA
0.84
Apr.
May
0.09
June
Aug.
Oct.
Kodiak
NEGOA

The first PC of the species data contrasted transects dominated by Sooty Shearwaters and Tufted Puffins with those dominated by Short-tailed Shearwaters and Fulmars. However, it accounted for only 36% of the total variation. The second component (contains 25% of the variability) seemed to represent a contrast between the distribution of Fork-tailed Petrels and Black-legged Kittiwakes with that of Short-tailed Shearwaters. The joint distribution of Fulmars and Short-tailed Shearwaters was represented by PC3 (19%), that of Fork-tailed Petrels and Short-tailed Shearwaters by PC4 (16%).

A high correlation (.69) between PC1 (SPP) and PC1 (ENV) suggested that the distribution of Sooty and Short-tailed Shearwaters, Tufted Puffins and Fulmars are formed in response, directly or indirectly (i.e., through the food resources), to the temperature-salinity gradient found over the continental shelf and slope (figure 49). This correlation confirmed other observations in the gulf suggesting that the Short-tailed Shearwater is more of a deep-water species than the Sooty Shearwater.

Canonical Correlation gave slightly different results. The first canonical variable (CC1) showed a very high correlation (.99) between a temperature-depth gradient and the distribution of Sooty Shearwaters and Tufted Puffins (figure 50). The other original variables had low correlations with CC1. The second canonical variable relates Black-legged Kittiwake density to temperature[1] (v=.97), with very little contribution from depth or salinity (Fig. 51). The third canonical variable relates a salinity-depth gradient to the distribution of Short-tailed Shearwaters and Fulmars (figure 52).

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1. The first component is the linear combination of the original variable that best discriminates between transects. The second component expresses the next most prominent pattern in the data that is uncorrelated with the first.

FIRST PRINCIPAL COMPONENTS (CORRELATION = .69)

GRAPHS NOT REPRODUCIBLE

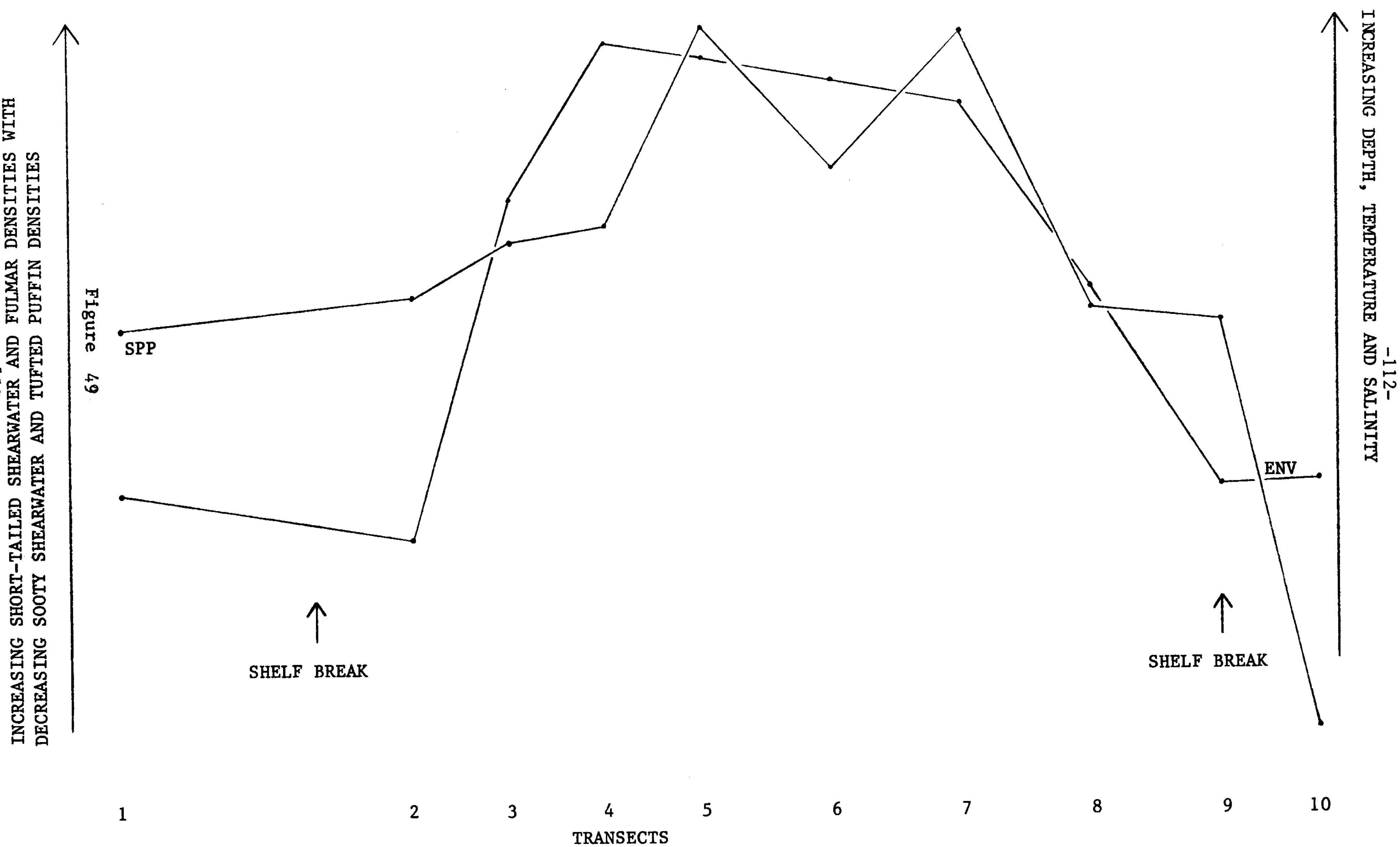

Figure 49

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FIRST CANONICAL VARIABLE (CANONICAL CORRELATION = .99)

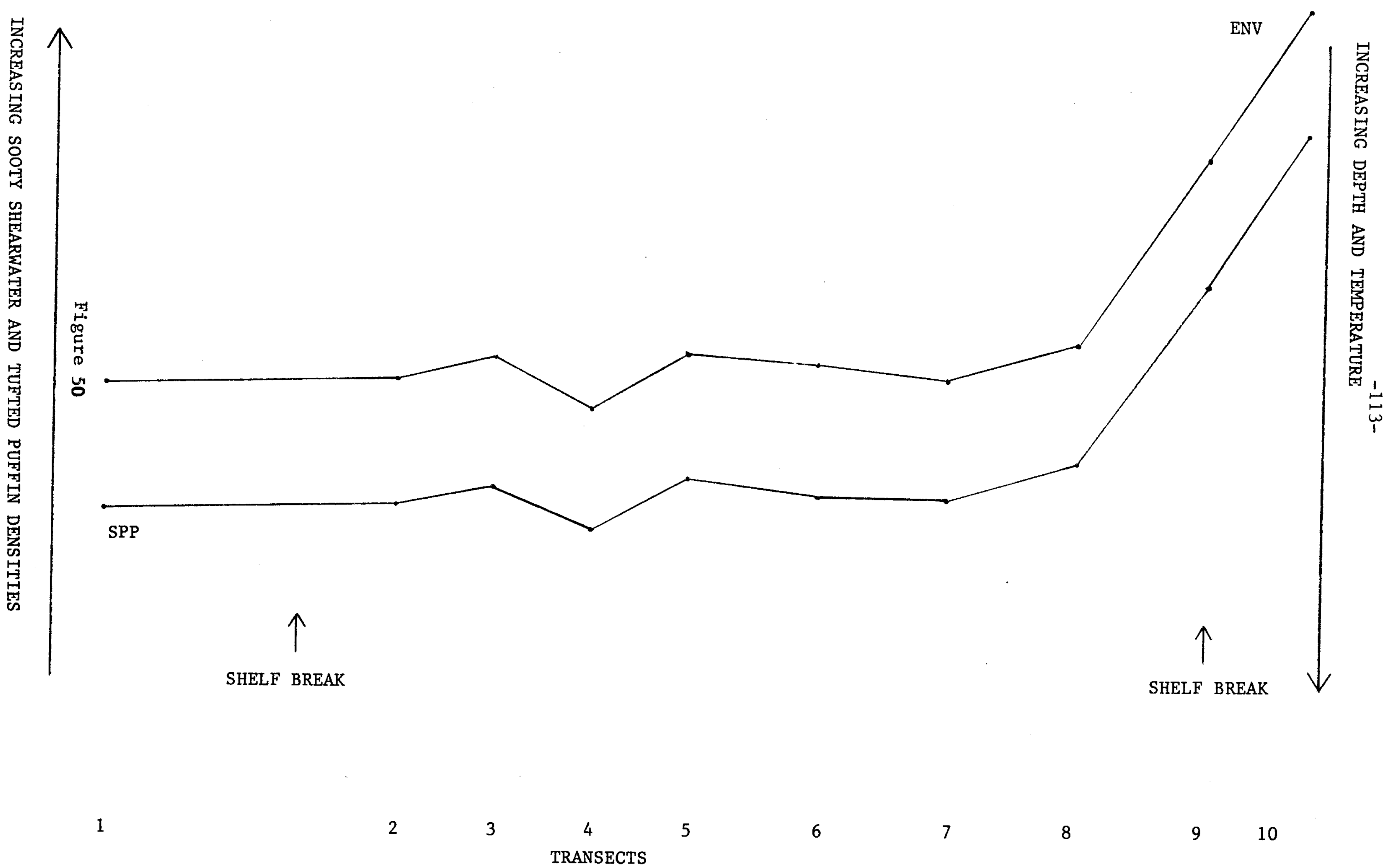

Figure 50

SECOND CANONICAL VARIABLE (CANONICAL CORRELATION = -.97)

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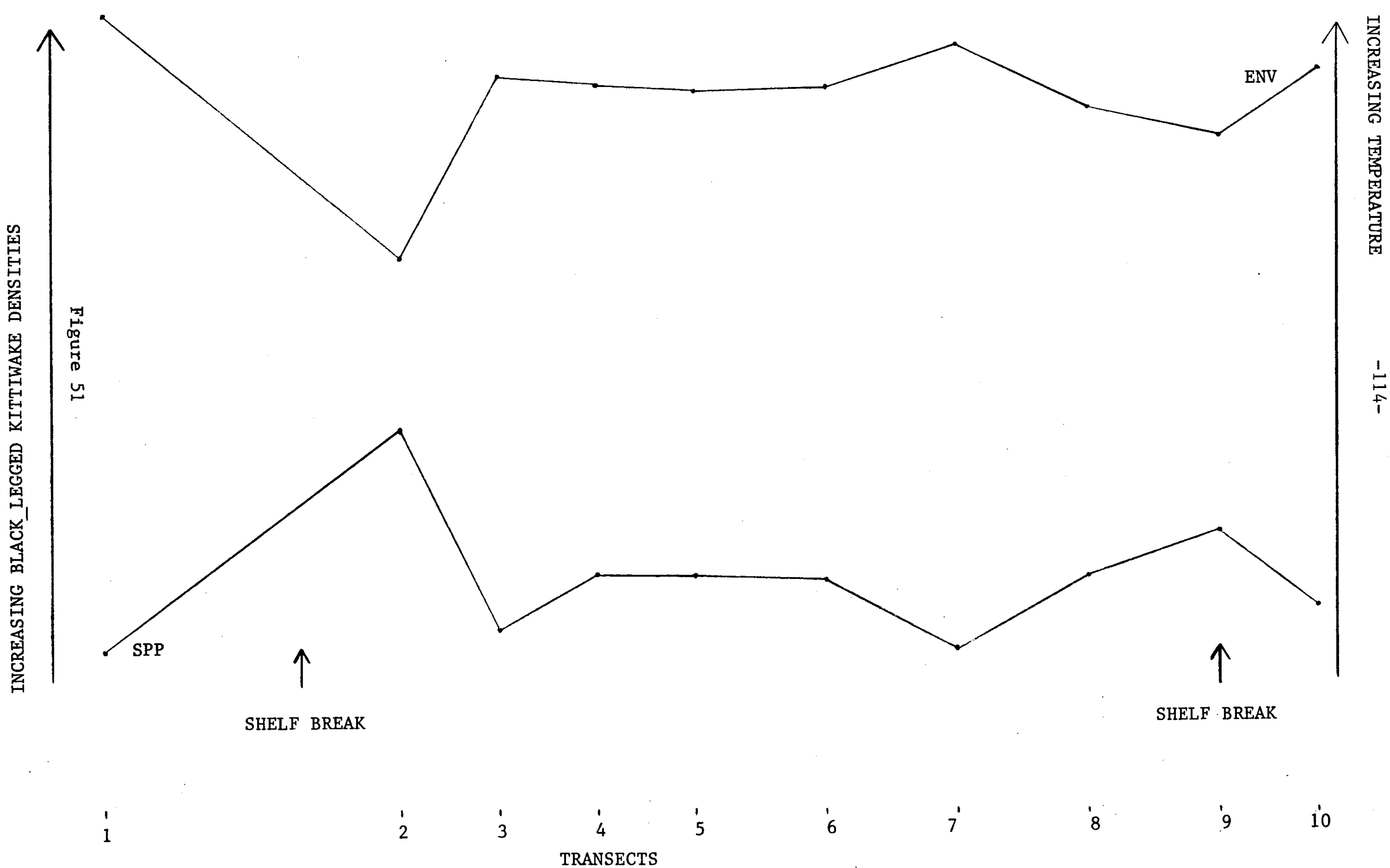


Figure 51

These results suggest that Sooty Shearwaters and Tufted Puffins were avoiding the off-shelf waters in response to temperature, while Short-tailed Shearwaters and Fulmars avoided the shelf in response to salinity. It appears from figure 5[1] that Black-legged Kittiwakes prefer the areas of slightly colder water over the shelf break, where upwelling may be an important factor affecting productivity.

The strong correlations between the environmental variability and densities for all species, except for Fork-tailed Petrel, indicate that the birds are distributed in direct response to food sources, or are monitering temperature and salinity to locate prey concentrations. The latter process depends on a temporally and spatially predictable correlation between prey distributions and temperature or salinity gradients. Current research (R.U. 341) indicates that Sooty Shearwaters are primarily piscivorous while Short-tails feed primarily on euphausiids. This would only be true if fish are energetically a more desirable food source. Unfortunately, we have no data to evaluate the relative quality of bait-fish versus euphausiids, in relation to their availability and the energetic cost for location and capture of each prey type. In light of their extensive migration, and their North Pacific-wide distribution, it is difficult to believe that Short-tails are physiologically excluded from inshore areas which differ from offshore waters, in our sample, by one degree centigrade or less. Indeed we have often observed them feeding close to shore on fish, near to or with Sooties. That they might be competitively excluded is suggested by the fact that Short-tails take smaller prey items (Sanger, R.U. 341), but we have not seen evidence that when feeding in the same area they take different sizes of the same prey type. The prey size difference may be unrelated to competitive interactions, as Sooties have larger bills and the fish are on the average larger than euphusiids. If Short-tails

THIRD CANONICAL VARIABLE (CANONICAL CORRELATION = .72)

GRAPHS NOT REPRODUCIBLE

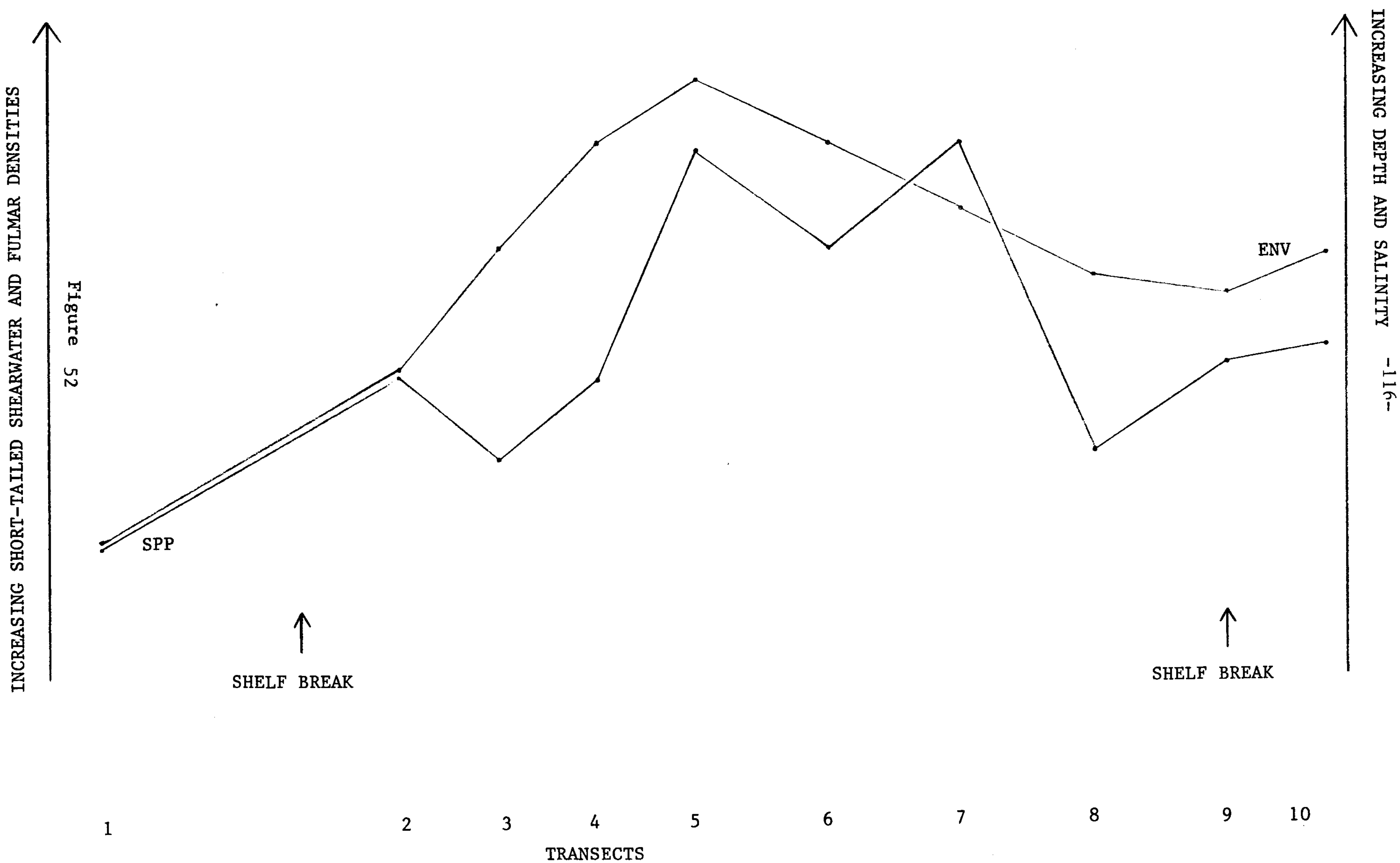


Figure 52

prefer euphausiids then their distribution is understandable, as euphausiid densities are known to peak over the continental slope. These patterns are by no means universal, but we have observed them at other times of the year and in other areas of the gulf.

OTHER SAMPLING ACTIVITIES

During a cruise aboard the R/V Moana Wave in late October 1976 we had the opportunity to conduct several supplementary tests of transect census methodology, and to add to our information on the distribution and abundance of several species. These additional findings are summarized here.

First, the cruise provided an opportunity to intercalibrate transect census methodologies. A total of 21 transects were conducted by Wayne Hoffman and Terry Wahl of our group simultaneously with U.S. Fish and Wildlife transects conducted by Patrick Gould. Determination of the comparability of the results of these census techniques awaits calculation of density estimates from the cruise.

Second, we used a second observed (Terry Wahl) who was familiar with marine birds but not with our transect censusing techniques to test the ability of other observers to learn this method. During the first 30-min transect, Wahl recorded 40-50% of an experienced observer's (Wayne Hoffman) efficiency; during the fourth 30-min transect, this efficiency increased to 80%. This suggests that a good observer with some familiarity with marine birds can be taught this method in one day under favorable conditions, and that an inexperienced observer should be able to learn the method without help as fast as field identification of the birds can be mastered.

Finally, we recorded information on the southern limits at this time of year of the distributions of several species normally present in the Gulf of Alaska. Table 17 presents the southern extents of the observed occurrences of nine species along the 158th meridian in late October-early November.

Table 17. Southern extents of the observed occurrence of nine species along the 158th meridian, 22 October-6 November 1976.

Species	Southern Limit	Comments
Northern Fulmar	36° 29' N	Rare south of 43°, common north
Mottled Petrel	36° 29' N	Common north of 45°
Fork-tailed Storm-petrel	49° 30' N	
Leach's Storm-petrel	26° 40' N	Rare south of 45°, common north
Red Phalarope	27° 48' N	Abundant between 42° and 40° 50' N, rare elsewhere
Glaucous-winged Gull	33° 47' N	Rare south of 40°, common north
Black-legged Kittiwake	41° 21' N	Common north of 45°
Horned Puffin	45° 00' N	Abrupt boundary
Tufted Puffin	41° 42' N	Rare south of 45°, common north

MIXED-SPECIES FEEDING FLOCK COMPOSITION AND ORGANIZATION

Fish-eating seabirds in most of the world's oceans aggregate into multi-species flocks to exploit fish schools and other clumped food sources. These flocks often include members of several species with different feeding methods (Gould 1971, Scott 1973, Sealy 1973) that may appear to be complementary. We have been studying these flocks in the temperate and subarctic Northeast Pacific, emphasizing the role of flocking in the organization of the avian community. We have concentrated on interspecies interactions of the birds with their prey in order to explore whether the flock-feeding birds are a coevolved interdependent assemblage or whether they are ecologically relatively independent of one another.

We define "feeding flock" slightly differently than previous authors. Morse (1970) defined a flock as "any group of two or more birds, whose formation depends upon positive responses by individuals to members of their own or other species" in contrast to an aggregation, which is "a group of individuals that is drawn together only by some extrinsic factor such as a localized food or water source." Although these definitions seem inclusive, the associations we studied lie between the two categories. They form over, and in response to, localized fish schools, but as we demonstrate below the birds themselves provide the primary indicators of the presence of fish schools. Therefore, we define a "feeding flock" as a group of two or more birds feeding on a localized patch or clump of food resources, but which formed when individual birds responded positively to other feeding birds. Feeding flocks are separable from the foraging flocks common in terrestrial insectivorous birds (Morse, 1970), which search for dispersed food as a group. The birds involved in feeding flocks, on the other hand, search separately for clumped food resources, and the flock forms once the food source is located.

Terrestrial mixed species flocks may be adaptive because group foraging is more efficient (Murton 1971), because predator detection is more effective in groups (Hamilton 1971, Pulliam 1973, Vine 1973), or through a combination of the two (Morse 1970). The marine flocks we studied appear to have no antipredator function, as the larger marine birds are quite free of predation while at sea, so we directed our attention strictly to aspects of foraging performance. Here we describe flock development and organization and explore the relationships and degrees of dependency between the various species. The thrust of the analysis is to assess the effects of the various species on the stability, longevity, and efficiency of the flocks. This approach is justified by the assumption that when a fish school is located, maximum benefit is derived by all of the participating birds if contact with the fish is maintained as long as possible, while maintaining a high individual capture rate.

Methods

Study Areas and Observations.- Our studies in the Gulf of Alaska were conducted primarily during the summers of 1975 and 1976. In early August 1975 Chiniak Bay and the waters just east of Woody Island, near the village of Kodiak, were explored intensively. Data were also collected during August at Sundstrom Island, several places in the Shumagin Islands, and in Unalaska Bay. We also observed Chiniak Bay flocks in late September 1975. Locations at which feeding flock data were gathered are shown in Fig. 53.

In extensive nearshore operations around Kodiak Island in May 1976 we demonstrated that feeding flocks were uncommon at that season. We conducted extensive vessel-based studies in the nearshore waters around Kodiak Island, in the Semidi and Shumagin Islands, and in Unalaska Bay in July and early August 1976, and intensive shore-based studies of flocks at Chowiet Island

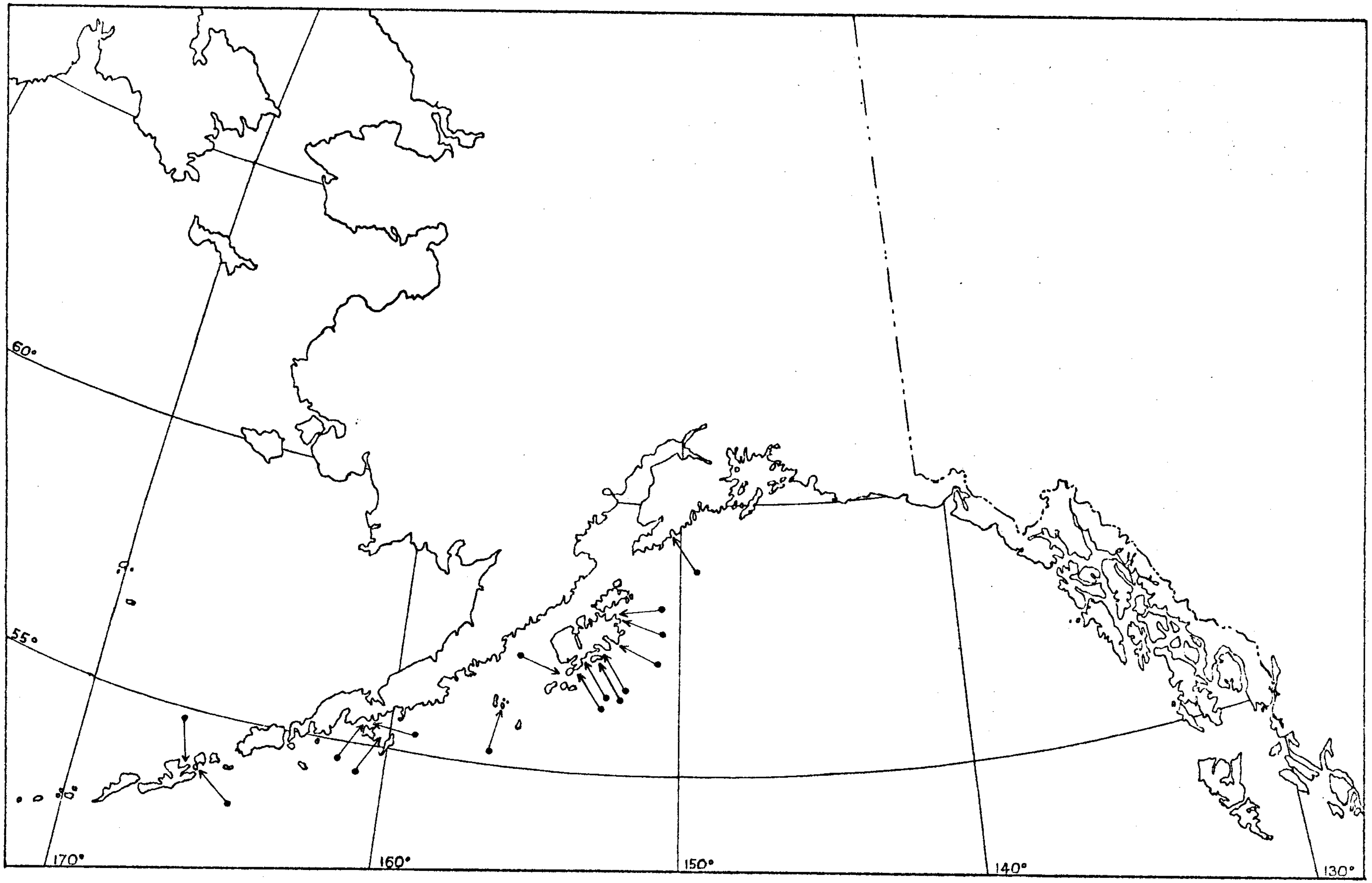


Figure 53. Locations at which observations of marine bird foraging flocks were made.

in the Semidi group, at Kodiak, and at East Unalga Island, in the Eastern Aleutians, in August and September 1976.

In addition, W. H. observed 65 flocks at Destruction Island, Washington, in May-July 1974, and also made casual observations of a number of flocks elsewhere along the Washington and Oregon coasts over several years. We occasionally refer to these data for comparative purposes.

We observed the flocks from the research vessels Surveyor and Acona, from smaller launches carried aboard those vessels, and from land at several sites overlooking areas of flock activity. The larger vessels were useful for determining the overall distribution of feeding flocks, but usually were unsuitable for detailed observation. The smaller launches were used for detailed study in protected waters and for collection of birds. Land-based studies involved very detailed observations of flocking in limited areas.

The Surveyor's launches are 10-m craft with covered cabins and are capable of about 8 knots. We normally sat on the foredeck or the cabin roof for flock observation so our eye level was about 2 m above the water. The R/V Acona is a 27-m vessel capable of about 10 knots. We collected flock data from the fore and aft deck, where eye level was about 4 m above the waterline. We also made extensive use of a 16-foot (5-m) Boston Whaler that was carried on the deck of the Acona. All shipboard observations were made with 8X or 10X binoculars.

Land-based observations were made from points or headlands overlooking the ocean, often 20 m or more above the waterline. A 20X-45X spotting scope was used as well as binoculars. We recorded our observations with portable tape recorders for later transcription.

Data Collected.- For each flock we recorded location information, a time course, flock configuration data, a variety of behavioral data, and environmental conditions. The location information included position relative to nearby landmarks, distance from the observer, and water depth, if known.

The time course included the time the flock began forming or was discovered and times (to the nearest 1.0 s) of all events recorded in the flock. The flock configuration data included estimates of size, shape, numbers, and distribution within the flock of each species. If the flock as a whole was moving, its direction was recorded.

We stressed behavioral observations in our data collection. For each species we recorded arrivals and departures, vertical and horizontal position within and around the flock, feeding methods and rates, and interactions, especially between members of different species.

When possible, the prey captured by flock members were noted. In a number of cases prey were identified, usually in the bills of birds. We also collected 36 birds for stomach analysis from the flocks. Any marine mammals associated with flocks were noted and counted, as flocks often formed over feeding pinnipeds.

We were not able to record all of these data for any one flock, but we did obtain reasonable numbers of observations for most of them. The count data and behavioral interaction data were stressed, so we have more complete coverage for them.

Results

Flock Types.- The Alaskan feeding flocks can be grouped into three categories on the basis of size, longevity, and nature of the food source:

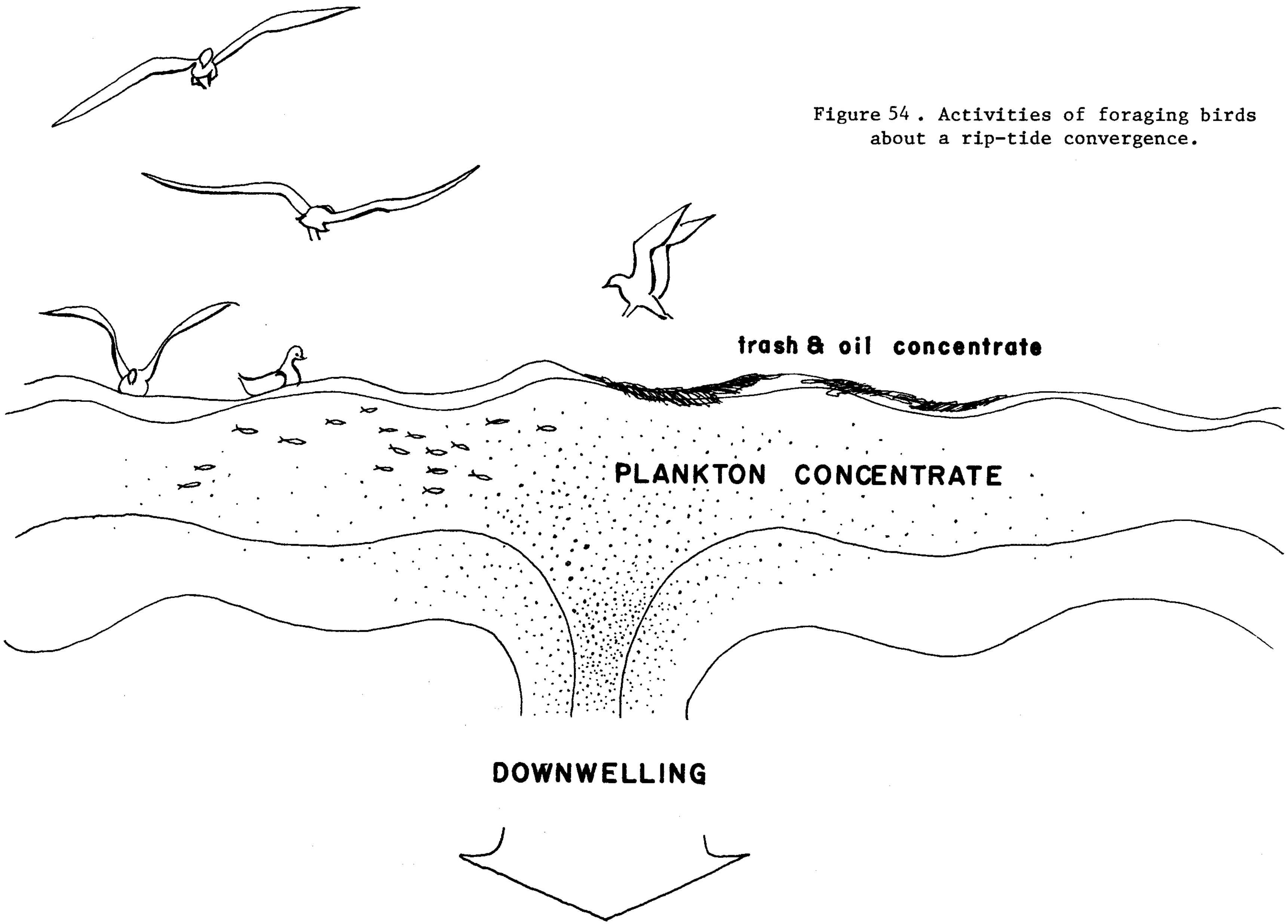
Type I flocks are relatively small (usually < 500, often < 50 individuals) short-lived aggregations that apparently form over cohesive fish schools. We presume them to begin with the discovery of schools at or near the surface, and to end when the schools descend below contact with the birds. In Alaska, gulls, kittiwakes, puffins, and cormorants (scientific names are given in Appendix I) predominate in these flocks. Type I flocks on the Washington and Oregon coasts are similar but frequently include Rhinoceros Auklets, Common Murres, and non-breeding loons. We observed a total of 210 Type I flocks.

Type II flocks are much larger (typically 5,000-50,000 or more individuals) and longer lasting. They form over concentrations of food organisms that apparently do not act as cohesive units. Thus the activities of the birds do not rapidly drive the food organisms down in the water column out of reach of the birds. These flocks may form over concentrations of fish such as capelin or perhaps over shoals of pelagic crustaceans. In Alaska the alcids tended to avoid Type II flocks. We have seen similar flocks off the Oregon and Washington coasts, apparently exploiting concentrations of Northern Anchovy (*Engraulis mordex*). Alcids occurred in these flocks much more frequently than in Alaska. We observed 30 Type II flocks.

Type III flocks, or rip flocks, form where local water mass discontinuities involving downwelling (rips) apparently act to concentrate zooplankton and small fish (Fig. 54). In Alaska these rips are commonest in island archaepelagos and off headlands, where tidal currents flowing around the land meet and coalesce downstream from the obstructions. The duration of the flocks is thus limited by the tidal cycle. Type III flocks occurred daily in several places in the Semidi islands and in the waters around East Unalga. Murres, puffins, auklets, shearwaters, fulmars, storm-petrels, kittiwakes, and gulls all gather in the Alaska rip flocks. Gould (1971:16-25) and Ashmole (1971:248) have described seabirds feeding at similar but much larger and more persistent hydrographic features in the tropical Pacific.

The Food Sources.- Sandlance (*Ammodytes* sp.), herring (*Clupea harengus*) and various smelts (Osmeridae) are probably the most important baitfishes exploited by Alaskan Type I flocks, although in the absence of definitive food habits studies of feeding flocks such a claim must remain conjecture. These prey all have the morphological features typical of small midwater schooling fishes (Parr 1927): large laterally-facing eyes, an elongate cylindrical or moderately

Figure 54 . Activities of foraging birds about a rip-tide convergence.



compressed shape, oceanic countershading coloration (blue or green back, silvery or white underparts), and a general absence of active defensive adaptations (i.e. no spines, toxins, inflation capabilities, or aggressive defensive behaviors).

Type II flocks may exploit prey concentrations that are not cohesive, so the birds can feed for extended periods without driving off their prey. In southwestern Alaska, capelin-based Type II flocks are regular in summer around Kodiak and elsewhere along the Alaska Peninsula. Here the capelin gather into large spawning or post-spawning concentrations in fairly shallow water and remain for days. The fish tend to be on the average a meter or more apart, at least near the surface, so that individual escape reactions may not propogate throughout the concentration.

Other Type II flocks, dominated by shearwaters, feed on prey concentrations apparently dominated by euphausids and perhaps other pelagic crustaceans. These prey swarm to the surface in the evening and early morning, and the flocks are usually crepuscular or nocturnal. Some euphausids surface in swarms during the day, and the associated flocks may occur in the daytime. The swarms move actively, and as portions of them surface, thousands of shearwaters may plunge-dive into small areas, churning the water to froth. This of course decimates or disperses the prey at that spot, but the lobes of the swarm contantly reform and resurface so that the flock as a whole may feed for several hours.

Geographical Distribution of Feeding Flocks.- Although our study was limited largely to the area from Kodiak to Unalaska Island, similar flocks occur south and east to the coasts of British Columbia (Sealy 1973) and Washington, Oregon, and northern California (Scott 1973 and authors' personal observations). They are probably widespread in the western North Pacific and North Atlantic as well.

Type I feeding flocks were virtually limited to nearshore waters. All but one of the Type I flocks we analyzed were within 5 km of land. This is not due to sampling bias, as we spent extensive periods offshore during both summers. but it probably reflects the surface distribution of baitfish schools. Several of the participating bird species (Black-legged Kittiwakes, Glaucous-winged Gulls, Common Murres, Tufted Puffins) were regularly seen at greater distances from shore, but then they either fed alone or gathered about ships' garbage.

This flock distribution is very different from that of flocks in pelagic areas of the central Pacific studied by Gould (1971, and in King 1974). Those feeding flocks formed far offshore as well as near land, over schools of baitfishes or squid driven to the surface by tuna and/or porpoises.

The Type II flocks that were apparently feeding upon capelin occurred within 5 km of shore, but usually at least 1 km out. This suggests that the capelin swarms are also nearshore phenomena, although this inference drawn from the feeding habits of the birds remains to be tested. The other Type II flocks, composed of shearwaters and apparently feeding on crustaceans, were often within a few km of land, but sometimes occurred much farther offshore. In some areas they may occur regularly along the continental shelf margin, where bathymetric deflection of currents increases vertical mixing, so that surface waters have increased productivity. The Type II flocks we observed along the Oregon and Washington coasts were also within a few km of shore, but we do not have enough offshore experience in those areas to determine whether this is typical.

Within the coastal study areas feeding flocks were commonest in the areas of greatest coastline complexity. Along the southeast side of Kodiak Island, for example, flocks were frequent in the Chiniak Bay area, the Sitkalidak Strait area, and around Sitkinak Strait, but were much rarer in the topographically less complex areas, such as the south coasts of Sitkalidak and Sitkinak Islands. There are several reasons for this pattern. Areas of complex topography, such as fjord-cut land masses and island archaepelagos, generally contain more suitable breeding sites for seabirds. Topographically complex coastlines are as well normally associated with complex bathymetry, which induces vertical mixing and thus higher productivity of the water. Bait fishes concentrate in such areas because of the increased productivity, and because the frequent rips concentrate their prey. In addition, suitable spawning areas may be more plentiful for some baitfish in topographically complex areas. Type III flocks, of course, are limited to areas of sufficient bathymetric complexity to generate the rips they utilize.

Flock Composition.- The species compositions of the Destruction Island and Alaskan feeding flocks are summarized in Tables 18 and 19. Twenty-one species occurred in Destruction Island flocks, although 10 of these were recorded fewer than five times. A maximum of 13 species was recorded from a single flock. Seven species nesting in the area made up the bulk of most flocks and overall accounted for 93% of the participating individuals. Large gulls (Western, Glaucous-winged, and their hybrids) and Rhinoceros Auklets overall accounted for 32% of the participating individuals, and Common Murres, Tufted Puffins, and Pelagic and Brant's Cormorants collectively accounted for the remaining 29%. We recorded Pigeon Guillemots twice and two other residents of the area, Marbled Murrelets and Fork-tailed Storm-petrels, once each. The remaining 7% of the individuals were distributed among 11 species of migrants. Sooty Shearwaters accounted for the majority of these. Heerman's Gulls took part extensively when they were present but only appeared at Destruction Island in

Table 18. Species occurrences in foraging flocks at Destruction Island, Washington (N=53).

Species	Frequency (%)	Abundance (Range)	S
Common Loon	15.4	1.63 (1-4)	1.06
Arctic Loon	42.3	7.05 (1-25)	6.38
Red-throated Loon	3.8	1	0
Buller's Shearwater	1.9	1	-
Sooty Shearwater	32.7	44.53 (1-200)	61.11
Fork-tailed Storm Petrel	1.9	1	-
Double-crested Cormorant	1.9	1	-
Brant's Cormorant	25.0	12.92 (1-60)	19.06
Pelagic Cormorant	44.2	28.65 (4-105)	27.83
Cormorant Sp.[a]	75.0	33.03 (3-110)	29.62
Glaucous-winged-Western Gulls[b]	100.0	67.98 (2-400)	81.49
California Gull[c]	1.9	1	-
Bonaparte's Gull	7.7	17.75 (1-54)	25.05
Heerman's Gull	13.5	70.29 (20-150)	53.05
Black-legged Kittiwake	3.8	3.0 (1-5)	2.8
Sabine's Gull	1.9	1	-
Common Murre	71.2	28.35 (1-80)	19.81
Pigeon Guillemot	3.8	1	-
Marbled Murrelet	1.9	1	-
Rhinoceros Auklet	98.1	70.39 (1-300)	70.62
Tufted Puffin	63.5	23.61 (2-95)	25.90

[a]Cormorant sp. includes the identified cormoratns plus unidentified cormorants in 13 flocks.

[b]Glaucous-winged and Western Gulls hybridize extensively at Destruction Island, so it was impossible to count GW, Wn, Hybrids separately in the flocks.

[c]A few California Gulls may be counted in the Glaucous-winged-Western category.

July, toward the end of the data collection period. Loons were regular participants but in low numbers. The others were rarely participants and appear to be of no functional importance to the flocks.

The composition of the Alaskan flocks shows a strikingly different pattern. Although we have composition data on three times as many flocks, gathered from a much wider geographic area, only 18 species were recorded taking part. Gulls accounted for 38% of the flock participants (27% Black-legged Kittiwakes, 11% Glaucous-winged Gulls, a few Mew Gulls, and one red-legged Kittiwake). Cormorants were less regular and less common in the flocks than at Destruction Island. Most of the species were breeding in the study area, but the two migrant shearwater species accounted for 25% of all individuals seen.

Individual Type I flocks in Alaska tended to be smaller and to have fewer species than at Destruction Island. The mean number of species in the Alaskan flocks was 2.79 (range 1-6) in contrast to 5.54 (range 1-13) at Destruction Island ($t=8.716$, 103 d.f. $P < .001$).

The Alaskan flocks averaged 88.13 (range 2-995) individuals and the Destruction Island flocks, 211.96 (range 4-590) individuals ($t=3.89$, 207 d.f. $P<.001$). The difference in flock size may be largely due to the greater duration of Destruction Island flocks (av. 819 s vs. 100 s at Chowiet; unpaired t, unequal variances=5.46, $P<.001$) and partly to the fact that many of the Alaskan observations were taken in restricted bays and channels with relatively small bird populations.

The lower species richness of the Alaskan flocks is largely due to the absence of Northern Hemisphere migrants. The midwater-fish eating segments of the nesting communities are of similar size, although overall the Alaskan seabird community is much richer. For example, 7 of at least 19 breeding seabird species in the Semidi Islands were regular foragers on midwater baitfish, while 7 of only 13 species on the Washington coast utilized this

Table 19. Species occurrences in Type I flocks in several Alaskan areas.

Species	Frequency (%)	Abundance (Range)	S
KODIAK AUG. 1975 (N=10)			
Sooty Shearwater	10	3	-
Cormorants	30	41.67 (25-70)	24.66
Glaucous-winged Gull	50	51.40 (3-120)	49.28
Mew Gull	10	1	-
Black-legged Kittiwake	90	52.20 (10-200)	64.52
Common Murre	10	1	-
Horned Puffin	40	8.75 (5-15)	4.79
Tufted Puffin	70	55.57 (4-100)	37.02
KODIAK SEPT. 1975 (N=8)			
Sooty Shearwater	12.5	3	-
Short-tailed Shearwater	100	273.75 (60-800)	265.38
Black-legged Kittiwake	75	20.33 (2-60)	21.79
KODIAK-WHALEBOAT AUG. 1976 (N=11)			
Sooty Shearwater	9.1		-
Cormorants	45.5	4.20 (1-10)	3.56
Glaucous-winged Gull	18.2	9.00 (8-10)	1.41
Black-legged Kittiwake	90.9	24.80 (2-80)	24.84
Common Murre	9.1	5	-

Rhinoceros Auklet	9.1	6	-
Horned Puffin	45.5	26.80 (2-63)	24.81
Tufted Puffin	81.8	6.56 (1-20)	7.92
CHOWIET (N=39)			
Fulmar	17.9	1.29 (1-2)	0.49
Glaucous-winged Gull	46.2	5.00 (1-20)	5.04
Black-legged Kittiwake	89.7	29.97 (2-85)	23.67
Common Murre	2.6	2	-
Thick-billed Murre	2.6	1	-
Horned Puffin	97.4	33.24 (1-200)	33.67
Tufted Puffin	46.2	3.00 (1-10)	2.87
UNALASKA 1975 (N=21)			
Cormorants	52.4	118.73 (1-750)	256.66
Parasitic Jaeger	4.8	1	-
Glaucous-winged Gull	76.2	37.94 (3-200)	49.28
Mew Gull	4.8	1	-
Black-legged Kittiwake	85.7	31.56 (1-225)	50.31
Red-legged Kittiwake	4.8	1	-
Murres	9.5	11.50 (3-20)	12.02
Horned Puffin	61.9	10.15 (1-30)	9.02
Tufted Puffin	47.6	52.00 (3-200)	66.30
UNALASKA 1976 (N=6)			
Glaucous-winged Gull	100	74.67 (10-300)	112.48
Black-legged Kittiwake	83.3	26.20 (1-75)	31.30
Murre	66.7	4.75 (2-10)	3.59

Horned Puffin	16.6	3	-
Tufted Puffin	66.7	32.75 (6-75)	31.99
UNALGA (N=19)			
Short-tailed Shearwater	89.5	74.18 (5-200)	125.96
Black-legged Kittiwake	89.5	5.18 (3-45)	10.56
Tufted Puffin	15.8	29.00 (7-60)	27.62
KODIAK AUG. 1976 - FROM LAND (N=25)			
Cormorants	88.0	5.59 (1-12)	4.10
Glaucous-winged Gull	12.0	2.00 (1-3)	1.00
Black-legged Kittiwake	96.0	15.71 (3-40)	11.51
Horned Puffin	60.0	8.87 (1-55)	13.96
Tufted Puffin	4.0	2	-
SUNDSTROM ISLAND AUG 1975 (N=9)			
Cormorants	11.1	60	-
Pomarine Jaeger	11.1	1	-
Glaucous-winged Gull	11.1	15	-
Black-legged Kittiwake	100	26.33 (3-110)	37.37
Horned Puffin	11.1	10	-
Tufted Puffin	22.2	26.00 (4-50)	33.94
ACONA, JULY 1976 (N=7)			
Cormorant	14.3	14	-
Glaucous-winged Gull	42.9	28.33 (10-55)	23.63
Black-legged Kittiwake	100	50.86 (6-125)	45.79
Common Murre	14.3	2	-
Pigeon Guillemot	14.3	3	-

Marbled Murrelet	14.3	2	-
Horned Puffin	42.9	33.33 (10-50)	20.82
Tufted Puffin	42.9	35.00 (5-75)	35.06

resource. The differences in overall richness are largely due to the extra plankton feeders in the Alaskan communities.

Flock Structure.- Type I flocks exhibit a rather standard structure. Kittiwakes are mostly aerial, and form the bulk of the above-surface part of the flock. In calm air they usually form into a fairly circular group, but in wind the flock is usually elongated along the axis of the wind (this elongation was more pronounced in the Destruction Island flocks than in Alaska). Flocks often have one or more foci of intense kittiwake activity, corresponding to spots where portions of the fish school are closer to the surface.

These foci typically are short-lived in comparison to the flock as a whole. Diving birds are often distributed in particular patterns around the flocks. In Alaska, puffins tended to dive and surface in a circle around the area of kittiwake activity. Cormorants dove and surfaced in the center of the flocks, and actively joined the local foci of kittiwake feeding.

The Destruction Island flocks tended to be more complexly organized. Most were distinctly elongated along the axis of the wind, and the birds were arranged in a rather stereotyped pattern, gulls over the school. Loons surfaced and dove at the upwind end of the flock and between dives sat facing upwind, away from the rest of the flock. Rhinoceros Auklets and Tufted Puffins usually sat laterally to the gulls. Cormorants were typically located at the downwind end and in the interior of the flock. Many of the longer-lasting flocks moved considerable distances while remaining active. The loons appeared to lead the other birds, staying ahead of the general gull activity.

When the flocks did move, it was always upwind (n=6). This, and the consistent orientation of the flocks on the axis of the wind, indicates that the fish school orients in some way to the wind. The most likely orientation stimulus is the surface waves, which are perpendicular to the wind direction.

Type II flocks have less organization and complexity than Type I flocks. Gulls and kittiwakes feed almost exclusively from the air. Shearwaters mix with the gulls, but feed by pursuit plunging or pursuit diving. We could not detect any trends in flock shape, or any tendencies for particular species to occupy peripheral positions.

Type III flocks are also simply organized. They are elongate, since the rips they occupy are more or less linear structures. They may tend to have conspecifics grouped together, but we could not detect any pattern in the disperson of these groups.

Functional Roles of Species in Feeding Flocks.- We have grouped the species that participate in feeding flocks into four functional groups on the basis of the roles they play in flock organization (Table 20). These groups, catalysts, divers, kleptoparasites, and suppressors, are defined by their roles in flock organization, but correspond closely to different foraging tactics employed by the birds. The groups are not mutually exclusive, as some species perform dual roles and are placed into two groups.

Catalysts are birds whose foraging and feeding behaviors are highly visible. The various flocking species watch the catalysts and use their feeding behaviors as indicators of fish school presence. Catalysts are usually the initiators of feeding flocks, but when contact with a fish school is made by non-catalyst species, the arrival of a catalyst is necessary for rapid flock development. The most important catalysts in our study areas were gulls, especially Black-legged Kittiwakes and Glaucous-winged Gulls. They are capable of slow,

TABLE 20. FUNCTIONAL GROUPS

Catalysts	Divers	Kleptoparasites	Suppressors
Black-legged Kittiwake	Horned Puffin	Pomarine Jaeger	Short-tailed Shearwater
Glaucous-winged Gull	Pelagic Cormorant	Parasitic Jaeger	Sooty Shearwater
Herring Gull	Red-faced Cormorant	Black-legged Kittiwake	
Mew Gull	Tufted Puffin	Glaucous-winged Gull	
Sooty Shearwater	Common Murre	Long-tailed Jaeger	
Short-tailed Shearwater	Rhinoceros Auklet		
	Thick-billed Murre		
	Double-crested Cormorant		

highly maneuverable flight, that is probably energetically efficient (Tucker 1974) at least in relation to the rapid, more labored flight of the diving species. They are thus well adapted to searching for fish schools. They feed by aerial and surface plunging (see Appendix II for foraging behavior definitions) and are consequently highly visible while feeding. In addition, these gulls have largely white underparts and wing linings, so that their visibility is greatly increased. Darwin (1890) and Armstrong (1946) suggested that this coloration evolved for the "purpose" of attracting other birds to food sources (see Simmons 1972 for a recent revival of this hypothesis). The shearwaters occasionally were used as fish school location cues, primarily by kittiwakes and other shearwaters, so they also can be considered catalysts.

The diver category contains birds that forage by the "pursuit diving" and "pursuit plunging" methods. The larger Alcidae (auks) and the smaller Phalacrocoracidae (cormorants) are important divers in Alaskan feeding flocks. In addition, when small numbers of shearwaters (*Puffinus griseus* and *P. tenuirostris*) join flocks they function as divers.

Kleptoparasitism is the pirating of fish or other food from other birds. Jaegers exploit flocks only in this manner, but gulls and kittiwakes (catalysts) are also facultative kleptoparasites. Although kittiwakes and gulls obtain most of their food in flocks by aerial and surface plunging, they also regularly attempt to rob each other and other birds. Kleptoparasitism is probably not destabilizing to flocks, and in some circumstances (see below) may be important in maintaining overall flock efficiency.

Suppressors are species whose feeding sharply decreases the availability of prey to the other flock members. Sooty and Short-tailed Shearwaters were the two important suppressors of Alaskan flocks. Their noisy and disruptive feeding tactics (group pursuit plunging) appeared to disperse or decimate the food sources, and also may have interfered with the ability of the other birds to see their prey.

Flock Initiations.- The initiation of Type I feeding flocks follows a fairly regular pattern. Typically a single individual or a small group of birds detects the fish school and begins feeding. In most cases a catalyst locates the school. Of the 112 Alaskan Type I flock initiations we observed, 85 (76%) were by Black-legged Kittiwakes (Table 21). Five of seven initiations reported by Sealy (1973) were also by kittiwakes.

We only observed two initiations by Glaucous-winged Gulls in Alaska, although they were present in 36% of the flocks. However, Glaucous-winged and Western Gulls accounted for 10 of 13 flock initiations recorded on the Washington coast in 1974. In the presence of kittiwakes, Glaucous-winged Gulls seemed less active in searching for schools. When Alaskan flocks dispersed, kittiwakes normally left rather quickly and spread out into a widespread search pattern. The Glaucous-winged Gulls usually sat on the water at the old flock site for several minutes or until a new flock began nearby.

Cormorants and Horned Puffins were the only divers observed to initiate flocks. When they discovered fish schools, flock development was slow until a catalyst arrived and began feeding. For example, at Chowiet on 8 August 1976 W. H. observed a flock that started with three Horned Puffins diving. Two Glaucous-winged Gulls joined them and sat on the water. After 20 s (presumably when the fish school approached the surface) the gulls begin feeding, and the flock grew to about 50 birds in the next 20 s. The same morning several flocks initiated by kittiwakes were observed, and they each grew to 40-100 birds within the first 20 s.

We did not observe the initial steps in the formation of a Type II flock, but have no reason to suppose that they are fundamentally different from those

Table 21. Species roles in feeding flock initiations in Alaskan waters.

Species	Species Occurred in		Species Initiated Flock Formation		
	all flocks (N=221)	initiated flocks (N=112)	#	% all flocks	% flocks present in
Sooty Shearwater	18	3	1	0.9	33.3
Short-tailed Shearwater	32	27	9	8.0	33.3
Cormorants	74	31	2	1.8	6.5
Glaucous-winged Gull	81	23	2	1.8	8.7
Black-legged Kittiwake	204	101	85	75.9	84.2
Horned Puffin	112	52	7	6.3	13.5
Northern Sea Lion	8	4	4	3.6	100.0
Harbor Seal	2	2	2	1.8	100.0

of a Type I flock. The birds that first locate the food concentrations still would comprise a better source of cues to distant birds than the food source itself. The major differences between Type I and Type II flocks results from the size of the food source and its lack of reaction to the birds, rather than from any differences in formation.

Type III flocks form over hydrographic structures (tide rips) that are regular in occurrence and often are quite visible from a distance. Thus the birds may fly to the area of a rip directly in response to its physical appearance or from memory. However, within a concentration of birds along a rip, gulls and kittiwakes clearly respond to each other to join over local concentrations. The divers do not move up and down the rips in response to the gulls, but when they first approach a rip they apparently prefer to alight in places where the other divers are concentrated.

Initiation Cues.- The regular Type I participants respond in very specific ways to the behavior of Black-legged Kittiwakes. The response patterns demonstrate that the birds normally are able to distinguish searching kittiwakes from feeding kittiwakes, kittiwakes feeding on garbage from kittiwakes feeding on fish, and kittiwakes feeding on a single fish from kittiwakes feeding on fish schools. When no flocks are active in an area, kittiwakes spread out and fly about slowly 10-25m above the water, searching for food. They also watch each other and approach any bird whose behavior indicates possible food. Birds that circle, hover, or plunge attract other kittiwakes. The diving species have much more restricted diets than the kittiwakes, so they gain nothing by joining kittiwakes feeding on garbage or carrion. The responsiveness of the divers to feeding kittiwakes varied considerably from area to area and through the season.

Observations (by W. H. and J. A. W.) at Kodiak 26-29 August 1976 were of unusually selective birds so they best illustrate the birds' discriminative capabilities. When a kittiwake plunged, other kittiwakes responded immediately, but the Horned Puffins and cormorants (both Pelagic and Red-faced) did not move until the first kittiwake left the water. If it circled up over the spot, the divers flew or dove to it, but if it flew off they did not approach (Table 22).

The kittiwakes were feeding on fish schools and also on dispersed fishes. We interpreted the behavior of the first kittiwake leaving the water as an indication of which food source was being attacked. The behavior of the additional kittiwakes arriving supported this interpretation. If the first bird left without circling, the later arrivals did not plunge or circle, although they often did try to rob the first bird. When the first bird circled back over the site the other invariably circled and plunged, confirming that fish schools were present. Figure 55 illustrates the plunge of a kittiwake. The cues used by puffins and cormorants occur at steps 6-8. If the bird proceeds on (7) the divers do not respond but if it circles back (8) they do.

We also have observations (Fig. 56) of alcids using the direct flight of birds to a flock as a flock presence cue. In one case at Destruction Island, W. H. observed gulls feeding on a fish school to the south of the island. Rhinoceros Auklets off the southwest end of the island took off the water and flew to the flock. Other auklets flying past the northwest point of the island, and completely blocked from view of the flock, veered south around the island to follow the first auklets into the flock.

Common Murres and Horned Puffins were similarly observed to follow kittiwakes to a flock around the northwest point of Chowiet Island, Gould (1971) suggests that similar cueing on travelling birds extends the "drawing radius" of central Pacific flocks well beyond the range that the flocks are directly visible.

Table 22. Species' responses (%) to behavioral cues of Black-legged Kittiwakes in feeding flock formation

Species	Response	Kittiwake behavior		χ^2
		Plunge & Leave (N=54)	Plunge & Circle (N=26)	
Black-legged Kittiwake	Positive	94	100	0.36
	Negative	6	0	
Horned Puffin	Positive	0	73	47.80****
	Negative	100	27	
Cormorants	Positive	2	88	58.63****
	Negative	98	12	

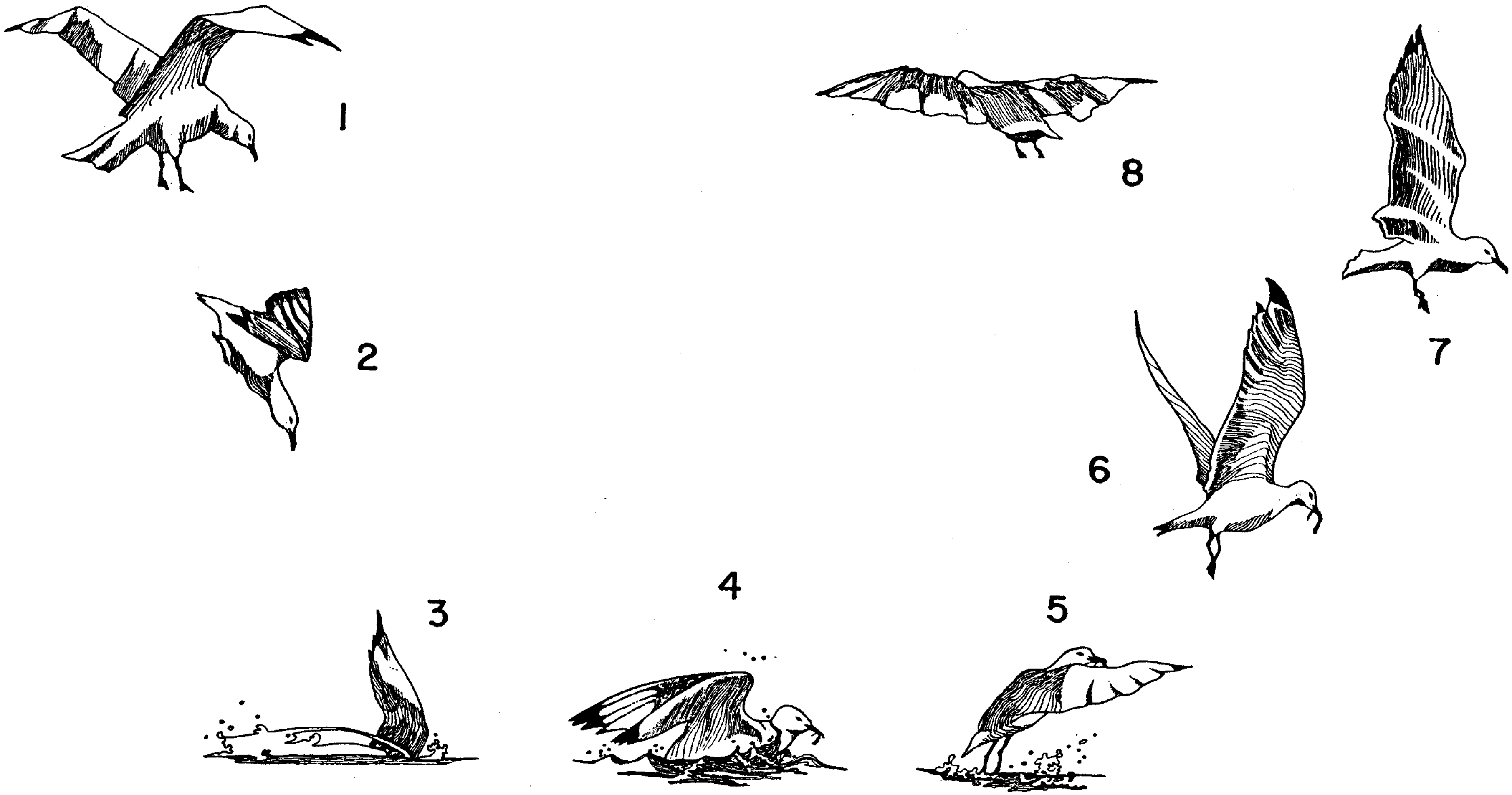


Fig. 55. Feeding plunge of a Black-legged Kittiwake. The characteristics of steps 6-8 are used as food location cues by other species participating in mixed-species feeding flocks.

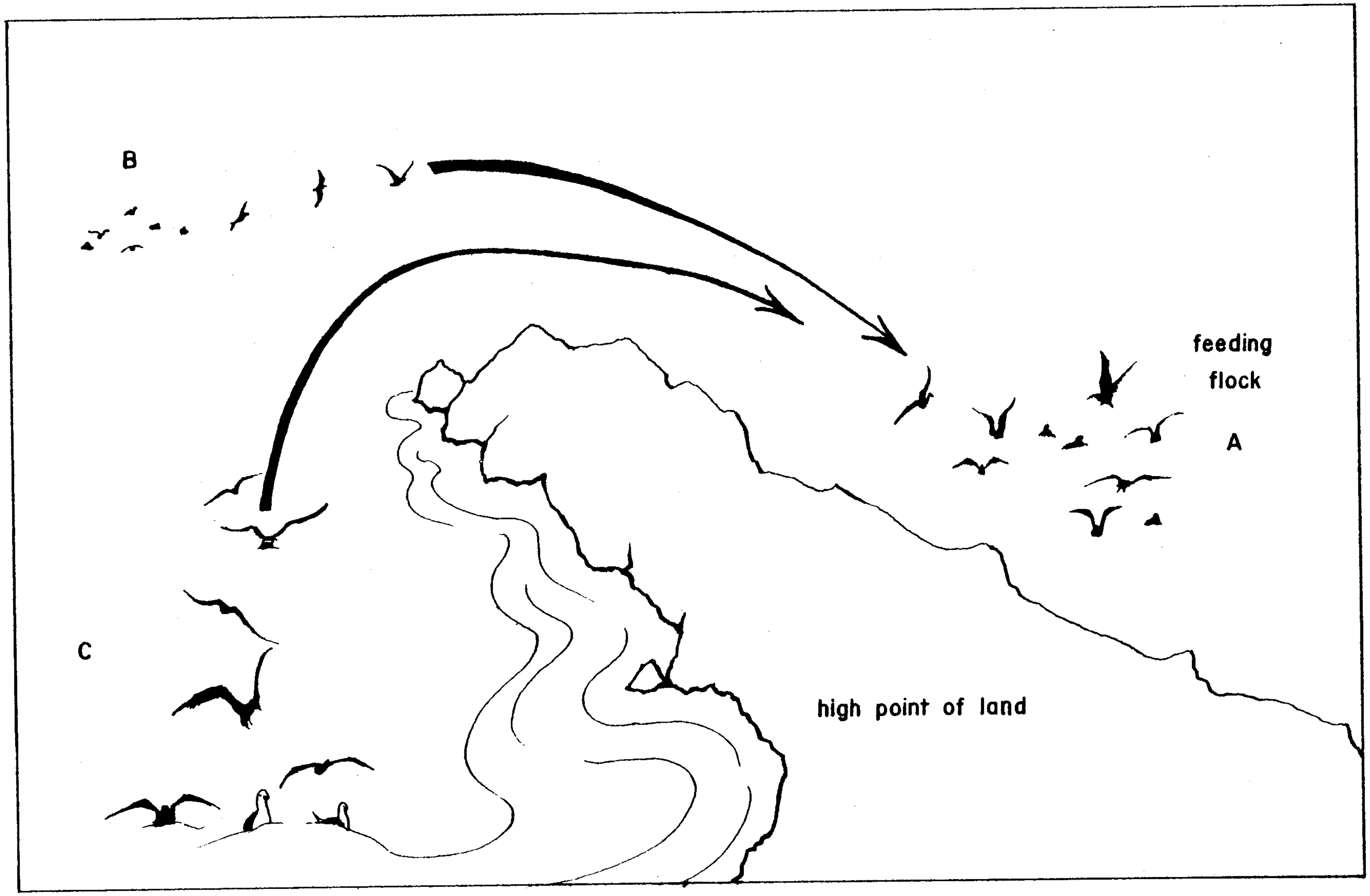


Figure 56. Feeding flock at A is observed by birds at B, which fly to join it. Birds at C cannot see the flock, but see the birds flying from B, and follow them to the flock.

Shearwaters used somewhat different cues in responding to birds locating fish schools. When they were present in large numbers, they frequently streamed through feeding grounds in relatively dense lines (Fig. 57) that might be several km in length. Stragglers spread out across the adjacent water. When a kittiwake or one of the stragglers plunged, apparently upon sighting a prey concentration, nearby members of the line turned and approached. Others in the line followed. Clearly many of the birds respond by following their neighbors rather than by independently flying to the flock (Fig. 57).

Flock Development.- Once a Type I flock has been initiated it develops following a fairly regular pattern. Gulls and kittiwakes fly in at 10-25m altitude. In wind they swing around to join the flock at the downwind end, but in calm air they approach from all directions, and begin searching as soon as they approach the flock. Alcids and cormorants fly in much lower, especially if they have flown off the water. Cormorants fly to the center of the flock, alight, and then dive. Alcids pursuit-plunge into the water at the boundaries of the flock and swim in under water. Nearby cormorants and alcids may dive toward the flock. Shearwaters fly to the center of the flock and pursuit-plunge. The flock builds until contact with the fish is apparently lost, or until all interested birds within sight have joined. Near colonies, long-lived flocks may reach an "equilibrium" where the number of birds coming in is equalled by the number of birds with prey loads returning to a colony.

Type II flock development is probably similar, at least on the first day. Because the area covered is much greater, the birds are probably initially much more spread out. Shearwaters remain in the area in rafts when satiated, and rejoin flocks as a group. They probably feed in the flocks twice daily, in the early morning and mid-late evening. Certainly in mid-day most of the shearwaters are typically resting on the water, with heavy loads of fish.

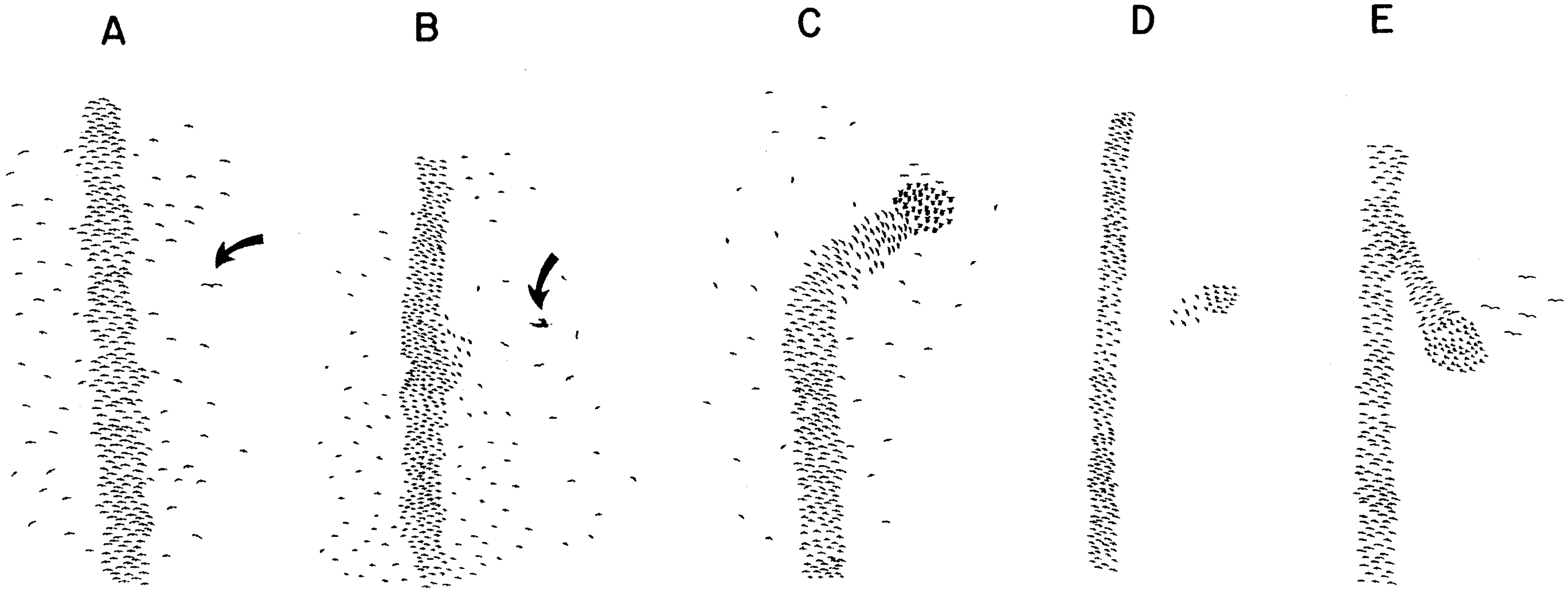


Fig. 57. Sequence of response of a shearwater flock (moving toward the top of the figure) to a foraging kittiwake (arrow).

Type III flocks develop after slack tides, as the rips develop. We did not detect any particular patterns of development. Birds flew in and landed in the forming rip as singles or more frequently in groups. After 60-120 min, numbers in a rip appeared to reach an equilibrium, with the numbers of birds joining the flock approximating the numbers returning to a colony.

Flock Decay.- Type I flocks follow a rather standard breakup pattern when contact with the fish school is lost. The kittiwakes and gulls lose contact first, since they must maintain visual contact from the air or the water surface. When they lose contact, some of the kittiwakes sit on the water at the site, but most gradually disperse outward, searching for a reappearance of the school, or for another school.

The Alaskan Glaucous-winged Gulls usually sat on the water after they lost contact, and waited for the kittiwakes to locate the next school, but at Destruction Island the Glaucous-winged and Western Gulls spread out and searched like kittiwakes. This difference is reflected in the initiation frequencies. Alaskan Glaucous-winged Gulls initiated only 6% of the flocks they took part in, but the large gulls at Destruction Island initiated most of their flocks.

The diving species normally make a few dives after the gulls lose contact but eventually lose contact themselves. A deep erratically moving fish school evidently can easily escape from the birds. The birds can no longer watch each other to relocate the school once it is too deep to be visible from the surface, so the fish need not lose all of the divers at once. When flocks are frequent, the divers do not search underwater for the school once they have lost it, but wait on the surface as the gulls search for other prey concentrations. When flocks are less frequent some of the divers may continue to search under water for several minutes after the school is lost. Rhinoceros Auklets at Destruction

Island and Horned Puffins at Kodiak were occasionally noted doing this. It was clear that at least some of the birds were searching for the school, because they gradually spread out from each other; if they had been in contact with the school they would have remained grouped.

We have not observed the breakup of Type II flocks. Type III flocks break up at slack tide when the associated rip disappears. The kittiwakes leave ripflocks before the alcids, but we were not able to define any other patterns in decay and breakup. Generally as the rip weakens the number of birds leaving toward the colony increases slightly and the rate of birds joining the flock drops abruptly.

Interactions of Flocks and Fish Schools.- Much of the behavior of the bird flocks is dictated by the actions of the fish schools. The schools are not generally vulnerable to birds until they approach the surface. They engage in frequent vertical movements, perhaps to escape predation by large fish, or possibly to reach surface plankton concentrations. When a flock forms over a school, the birds'activities may be intense enough to elicit escape reactions from the fish. These reactions propagate through the school, and eventually lead to the school sounding, initially out of reach of surface-feeding gulls, and eventually out of contact with diving birds. The speed of reaction of the school to the birds is related to its cohesiveness (Hunter 1969). A tight school, where all individuals are in close proximity, will be driven down by disturbance much faster than a looser school. Responsiveness is also related to fish size. Juvenile fish do not respond as readily to the activities of their neighbors as do adults (Shaw 1960, 1961, and W.H. personal observations) so escape behaviors do not propagate as readily in juvenile schools. This could be due to less well developed sense organs, to longer reaction times, or to the inability of small, slower swimming fish to generate strong stimuli to their neighbors.

Bird flocks feeding on schools of very small fish tend to persist longer than flocks feeding on adult fish schools.

Many of these attributes of the school must be inferred from the behavior of birds in the feeding flocks. The location, extent, and depth of the top of a school can be determined from a gull's position and behavior. Gulls over a school presumably circle only where they can see fish, and plunge only where fish are within about 1 m of the surface. Horizontal movements of the school are tracked by the birds as long as the school remains close to the surface. Flocks over juvenile schools frequently have rapidly shifting foci, although the flocks themselves persist. This indicates that disturbance of one part of the juvenile school does not readily propagate to the rest of the school, so the flock as a whole persists longer. The behavior of flocks feeding on larger (adult) fish is consistent with a more synchronous escape response by the school.

The hypothesis that schooling of fishes is an antipredator adaptation figures prominently in discussions of the adaptiveness of schooling (e.g., Brock and Riffenburg 1960, Clarke et al 1967). Brock and Riffenburg developed a geometrical proof that an aquatic predator should have greater difficulty finding tightly clustered prey than dispersed prey, and when it does find a school it can eat only a small part of it before becoming satiated. This may be an effective strategy against aquatic predators, but birds probably feed more successfully on schooling than dispersed fishes. Because birds watch each other and fly rapidly to any discovered school, the geometric advantages of schooling are circumvented. Our data demonstrate that schooling does not interfere with the birds'ability to select and capture individual prey; we have recorded 70-100% success rates by plunging kittiwakes and Glaucous-winged Gulls in flocks. Simmons (1972) described schools of larger fishes of Ascencion

Island in the tropical Atlantic that pack together very tightly and are not attacked by birds; the Alaskan baitfishes seem incapable of achieving this degree of packing. The persistence of schooling under these conditions suggests that birds are less important as predators than fish and aquatic mammals, or that schooling confers a different advantage in escaping bird predation. The ability of schools to descend rapidly when attacked may reduce their vulnerability. If baitfish approach the surface to feed, fish in schools may do so more safely because of their increased prdator detection capabilities over lone fish.

Effects of Kleptoparasitism on Flock Organization.- Kleptoparasitism is prevalent among gulls, and is the predominant foraging method of jaegers at sea. Jaegers do not have a major effect on feeding flock organization. They do approach flocks to attack kittiwakes, but this behavior has surprisingly small effects on the flock's functioning. Kittiwakes do not exhibit obvious escape maneuvers until the attack is initiated, and even then most of the birds in the flock do not react. The jaegers do not often enter large Type I flocks, but remain in the general area, and attack lone birds.

Our observations indicate that those jaegers that do enter the large flocks have a lower success at obtaining food (at least on a per-attack basis) than those that attack lone kittiwakes in the area. For example, on the afternoon of 25 July 1976 we observed a large flock feeding intermittently on capelin at Two-Headed Island, off the south shore of Kodiak Island. One Parasitic Jaeger entered the flock and attacked several kittiwakes. At each attack 3-5 kittiwakes followed the jaeger closely but did not interfere with either the jaeger or the chased kittiwake. In four consecutive attacks that occurred close to our vessel, the jaeger succeeded in forcing the kittiwake to regurgitate, but in each case, the following kittiwakes beat the jaeger to the regurgitated food and ate it themselves.

Pomarine Jaegers regularly joined the Type II capelin flocks, but foraged by a different "lower stakes" method of kleptoparasitism. They patrolled through the busy areas of the flock and preferentially attacked birds--kittiwakes and Sooty Shearwaters--that surface with fish in their bills. If the victim dropped its fish, the jaeger dropped to pick it up. Thus by dropping the one most recently caught fish, the victim could protect its (often considerable) load of swallowed fish. On 6 July 1976 at least 100 Pomarine Jaegers were present in a flock of around 10,000 kittiwakes and 40,000 Sooty Shearwaters. We were unable to detect any effects of their activity on the overall foraging rates of the flock.

Kleptoparasitism by gulls and kittiwakes had much more important consequences for Type I and Type II flock composition and organization than the jaeger's activities. Although they obtained most of their food by aerial plunging, the gulls and kittiwakes opportunistically attempted to rob a wide variety of birds. Since the fish-eating alcids carry fish to their nests in their beaks, they are vulnerable to robbery (e.g., Grant 1971, Nettleship 1972). The puffins and Rhinoceros Auklets are more vulnerable than the murres, because they carry several fish cross-ways in the bill, rather than one lengthwise and largely inside the bill. On the water they are quite successful at avoiding robbery by diving but occasionally they are robbed by a gull attacking just as the bird emerges at the end of a dive. The characteristic distribution of puffins and Rhinoceros Auklets around the perimeter of Type I flocks (see above, under Flock Structure) probably results from the divers attempting to surface away from the areas of maximum risk of robbery. The pattern is more apparent in flocks with very concentrated kittiwake plunging than in dispersed or less active flocks. It is also more apparent in flocks in which many of the gulls are sitting on the water or hop-plunging (usually flocks with more Glaucous-winged Gulls) than in flocks with most of the gulls in the air. This is probably because plunging or sitting gulls are much more visible to and thus more easily avoided by submerged divers.

This reaction of the alcids to kleptoparasitism may be very important to the overall performance of the flocks. Since the alcids dive and approach the fish schools laterally or from below they may have the effect of concentrating the school, or of preventing it from descending out of contact. If this is so, then it may contribute significantly to the length of time the school is accessible to the birds. Thus an aggressive, proximately destabilizing behavior of the gulls has the incidental effect of forcing the alcids to forage in a manner that probably stabilizes the flock, and increases food availability to all the birds (but especially to the gulls).

Cormorants tended to move to the centers of flocks and plunge there. Since they normally swallow their prey under water they are invulnerable to gull parasitism. Their foraging pattern is likely to have a destabilizing and shortening effect on the flocks but such destabilization would be difficult to detect. Our Type I flocks with cormorants are not noticeably shorter than flocks without cormorants, but since we have no control over, or even knowledge of, most of the other variables governing the fishes' reactions, the data are inconclusive.

Kleptoparasitism by gulls and kittiwakes may also be responsible for limiting the participation of alcids in Type II flocks. We observed several Type II flocks in an area (off Chiniak Bay, Kodiak) where puffins were common and were readily taking part in Type I flocks, but few of the puffins joined the Type II flocks, and those that did were mostly subadults.

Since the flocks are very large, puffins cannot swim in from the edges, and thus are continuously vulnerable to piracy. In all flocks, the frequency of kittiwake piracy attempts on all birds increased when the frequency of fishing plunges decreased. When given a choice, kittiwakes apparently prefer to catch their own fish (they are much better at it--overall success rates are around 60% for plunges, <10% for piracy) but when fish aren't immediately available they regularly try to rob other birds. Because the fish under Type II flocks are relatively dispersed, kittiwake piracy attempts on each other are more frequent than in other flocks (we observed piracy attempt rates as high as 50/hour/hundred birds in Type II flocks--rates were hard to determine in Type I flocks but much lower, < 10/hour/hundred). Murres and cormorants are less vulnerable to the kittiwakes, and both did participate in Type II flocks, but neither were common in the areas we studied.

Flock Suppression.- The two shearwaters are very gregarious and regularly travel in flocks of several hundred to many thousand birds. In Alaska they are strictly non-breeding migrants, although they are the most abundant Alaskan seabirds. They feed primarily by pursuit plunging. Typically, a flock sits on the water or flies as a group until a bird (a shearwater or gull) discovers a school of fish or a shoal of euphausids or other crustaceans at the surface. The entire flock may then fly to the site and plunge into the water. If the flock is large, birds continue flying in for as much as 20 to 30 s. Dive times can be obtained for these flocks because the birds surface quite simultaneously (generally within a 5 s period). Birds arriving after the flock has surfaced alight on the water. Few of the shearwaters ever make a second dive at the site. Instead, they sit on the water and wait for a new school to be located (or fly about searching for one). They normally do not dive to search for schools, but dive at schools located visually.

The combined activity of 500 or more birds simultaneously diving into a dense fish school must be to disperse it, drive it deeper in the water column, or decimate it. When flocks of shearwaters are feeding in an area in this way, they clearly prevent the normal formation of flocks. Some kittiwakes join the shearwater flocks, but typically they only forage for 5 to 10 s before the school is unavailable to them. Puffins and murres in the area do not attempt to join the massed attacks, but instead they dive solitarily or in small groups throughout the area. As an example, on 22 September 1975 the area of outer Chiniak Bay (Kodiak) between Long Island and Middle Bay contained about 5,000 Short-tailed Shearwaters, distributed in several discrete flocks of 500 to 800 birds, 1,000 to 2,000 Common Murres, several hundred puffins of both species, and 800 to 1,000 Black-legged Kittiwakes. Apparently all were feeding on juvenile fish (probably sandlance, Amodytes) which were schooling abundantly in the area Both the kittiwakes and the shearwaters were frequently locating schools, but each time a school was located, the nearest flock of shearwaters would fly into it in a period of 10 to 25 s. Kittiwakes generally flew to these sites, but were only able to feed for the first 5-10 s. We saw no attempts by the murres and puffins to join these melees. The suppressors clearly make flock participation unprofitable to the alcids, but if they disperse the fish schools, the success of individual foraging by the alcids might be increased.

Sooty Shearwaters also participate in the very large Type II flocks that gather over capelin concentrations. They do not suppress the flock organization in these flocks, apparently because the fish are already too dispersed to be effectively exploited by massed attacks.

The shearwaters (especially Short-tailed) apparently also feed in very large flocks (at times hundreds of thousands of birds) on pelagic crustaceans. Within a zone a few hundred meters to a kilometer or more wide, they wheel about in tremendous streams and plunge synchronously into the water. Tufted Puffins can regularly be seen in these areas but they dive solitarily and do not attempt to join the local shearwater concentrations. We have observed such flocks off Ugak Island (off Kodiak) on several occasions from mid-May through September, off Chirikof Island in September and October, in the eastern Aleutians throughout September, and irregularly elsewhere throughout the continental shelf areas of the Gulf of Alaska and the southern Bering Sea.

Community Interdependence on Feeding Flocks. - One of our initial objectives was to assess the degree of community interdependence in flock feeding. We have demonstrated that flocking is frequent through the nesting period, and that breeding individuals of several species regularly participate. The behavior of the major flocking species is complex and standardized, which suggests that it is very important to them. However, the possibility remains that alternative food sources exist, and that the birds could do quite well without the schooling baitfishes. W. H. collected feeding flock data that bear upon this question at Chowiet Island, Alaska, in August 1976. Simultaneously, USFWS personnel (Leschner & Burrell, pers. comm.) were studying the nestling growth rates and food habits of several of the seabirds breeding there. We observed that Type I flocks were scarce at Chowiet (only 55 flocks were observed in 19 days). Instead the puffins and murres were feeding primarily upon small juvenile *Amodytes* and other small fish in Type III flocks. Growth rates of the puffin chicks were lower than elsewhere, and fledgling weights of those chicks that did leave were approximately 100 g less than recorded elsewhere. Clearly, then, in the absence of the usually ubiquitous adult sandlance and the consequent lack of Type I flocks, nesting performance was markedly impaired at Chowiet.

In a situation where kittiwakes and Glaucous-winged Gulls were scarce, even if the schooling fishes were present, the puffins might have a difficult time locating schools and suffer similar impaired breeding success.

Related Feeding Flock Observations.- Additional observations of feeding flocks made by Range Bayer in late July 1976 shed some light on other aspects of this system in marine birds. Bayer concentrated his observations on feeding kittiwakes. Kittiwakes feed both in groups and solitarily, and if individual kittiwakes derive substantial benefits from truly cooperative feeding in groups one would expect the success of birds feeding in groups to be greater than that of individuals feeding alone. The observations (Table 23) do not support such a contention. Solitarily-feeding kittiwakes did not differ substantially in foraging success from those feeding in groups, regardless of the flight orientation used in feeding. More impressive, in fact, is the considerable day-to-day variation in success rates; this is to be expected, given differing weather conditions, oceanographic conditions, or prey dispersions on different days.

As we noted above, kittiwakes play a key role as "cue species" in the formation of mixed-species feeding flocks (especially Type I). The formation of such flocks is usually initiated by the feeding of individual kittiwakes, and Bayer's observations indicate that the first kittiwake to initiate feeding in a group has a substantially greater feeding success than the individuals which subsequently arrive to form the feeding group (Table 24). The lower success of later birds probably acts to limit the time duration of feeding flocks, and

Table 23. Comparison of foraging success between group and solitarily foraging kittiwakes (23 July located just outside of Kodiak; 24 July at Rolling Bay at Ship Rocks at Kodiak Island; 29 July between Nagai and Popof Islands.

		ALL ORIENTATIONS				PLUNGE ONLY		
		Sample Size	Plunge Success (%)	Stoop w/o Plunge (%)	Plunge Failures (%)	Sample Size	Success (%)	Failure (%)
Group	23 July	367	57.4	26.7	15.8	269	78.4	21.6
	24 July	141	56.0	24.8	19.1	106	75.2	24.8
	29 July	262	6.1	72.9	20.9	71	22.5	78.5
	Pooled 23/24/29 July	770	38.4	42.0	18.2	36	67.9	32.1
Solitary	Pooled 27-31 July	73	24.6	54.7	19.2	32	56.2	43.8

Table 24. Success of first individual kittiwakes at foraging groups compared to the success of other individuals in group for 38 groups on 29 July. (Group sizes: $\overline{X}$ = 5.00. SD = 3.00 and extremes 2-17. Location of groups between Nagai and Popof Islands.)

		ALL ORIENTATIONS				PLUNGES ONLY		
		Number of Observations	Successful Plunge	Stoop w/o Plunge	Unsuccessful Plunge	Number of Observations	Successful Plunges	Failures
First Individual	Total N	38	10	6	22	32	10	22
	%	100	26.3	15.7	57.8	100	31.3	68.7
Other Individuals	Total N	155	3	134	18	21	3	18
	%	100	1.9	86.5	11.6	100	14.3	85.7

possibly acts to limit the time of the first feeding bird eliciting escape responses in the prey concentrations. The duration of feeding groups is often short, but differs between days (Fig. 58).

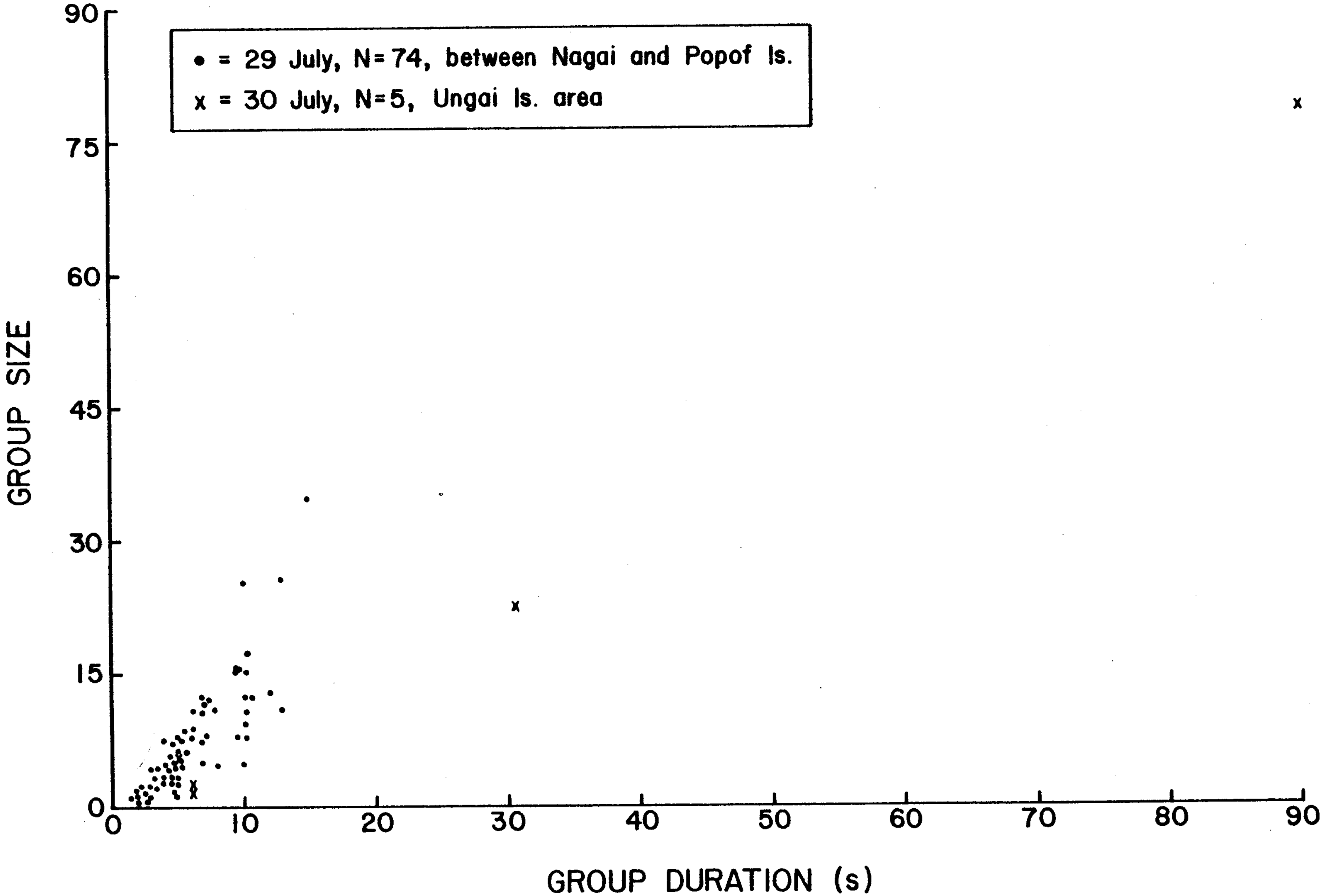


Fig. 58. Group size and duration for mixed-species foraging flocks on two different days.

POTENTIAL IMPACTS OF PETROLEUM DEVELOPMENT

Birds are among the most vagile and widespread of the consumers of marine ecosystems, and play especially important roles in linking terrestrial with oceanic systems and in transporting energy and nutrients in and between these ecosystems (Wiens and Scott 1975). It has been suggested (Weller and Norton 1977) that birds may indeed play vital roles in Alaskan marine ecosystems by recycling nutrients during seasons when oceanic circulation does not supply nutrients to photosynthetic strata, and thus "smooth out" the seasonal distribution of primary production. Additionally, birds may contribute to system stability by foraging on prey species that are temporarily abundant. These claims are as yet unsubstantiated, and are based upon theoretical arguments that are somewhat transparent, but the sheer abundance of birds in Alaskan nearshore and offshore waters argues for the importance of giving them careful attention.

Oil pollution may affect marine birds directly, through the loss of insulating properties of feathers, a reduction in swimming and/or diving abilities, ingestion of oil residues, a general deterioration of well-being because of reduced food intake resulting from oil effects, or reproductive losses due to oil contamination of eggs, among other effects. In addition, oil activities may produce indirect effects, through contamination of food, eradication of specific prey populations, or shifts in the composition of prey communities or in their aggregative tendencies. The very diversity of such petroleum-related effects makes clear prediction of the consequences of development an uncertain activity at best. Our studies of marine birds in Alaskan waters cannot at this stage provide definitive predictions of the specific effects that development of petroleum procurement, transport, and processing facilities and activities would have on bird populations, although some initial conclusions may be offered.

The two areas where petroleum development activities have begin in Alaskan waters, Lower Cook Inlet and NEGOA, clearly have lower overall species diversities and densities of marine birds than the other areas. Suitable breeding situations are less common in these areas, and food resource levels appear to be lower. The marine birds that do occur in these areas are almost all widespread species that occur in larger numbers elsewhere.

The as yet unbroken areas--Kodiak, NWGOA, and the Bering Sea-- have notably higher species numbers, bird densities, and breeding colony densities. They contain the princ-pal North American habitat of several uncommon or rare seabirds, most notably the Aleutian Tern, the Red-legged Kittiwake, and the Whiskered Auklet. Further, large aggregations of alcids occur here, and these species are especially susceptible to oil spills (Vermeer and Anweiler 1975). A spill in the Kodiak area in February and March 1970, for example, claimed an estimated 10,000 birds, and roughly 2/3 of the small sample identified were alcids, notably murres (Marine Pollution Bulletin 1970).

We suggest that the course of OCS petroleum development that would cause the least damage to seabird populations would be to concentrate development in the two areas already opened, the NEGOA and Lower Cook Inlet, and to avoid opening Kodiak, the NWGOA, and the Bering Sea for development. Kodiak and the NWGOA study areas probably do not differ greatly in the physical aspects of hazards to bird populations.

With respect to marine bird populations, the Bering Sea is easily the most important and most vulnerable to the effects of petroleum development. There are a number of reasons for this. The bird populations are larger, especially if the Aleutian passes (where Bering Sea oil must be shipped) are included. The water is colder, so floating oil will remain dangerous in the water for longer periods. Moreover, birds are most susceptible to oil fouling in cold situations (e.g., during winter months, Joensen 1972), when increased cooling may increase thermoregulatory metabolism costs and reduce foraging effectiveness, leading to death by accelerated starvation if not by exposure. Winter pack ice in the Bering Sea will inevitable cause problems for petroleum production, and will also interfere with any cleanup efforts on spills at the ice edge or in the pack. The eastern Aleutian passes will be hazardous areas for the passage of tankers, especially those of very large size, and the frequently inclement weather of the area will compound that problem. The likelihood of major spills or oil "disasters" thus seems greater in the Bering Sea than in other areas of the Gulf of Alaska. But while such major spills undoubtedly have profound and often spectacular and obvious effects upon the biological systems of the areas, minor pollution events associated with pertoleum development, production, and transport activities may also have important consequences. Reviewing the effects of petroleum on seabirds in Danish waters, Joensen (1972) observed that, apart from a few cases, most oil-caused mortality of seabirds was due to pollution that in other respects went unnoticed, and was simply a result of increased traffic and activity. These small-scale pollution events may be quite localized in space and time, and thus at many times perhaps of little overall consequence. However, even small-scale oil releases occurring, say, in waters adjacent to a breeding colony, or in zones frequented by spawning aggregations of prey species, could have major and lasting consequences, especially in some of the alcids and gulls that have distributions restricted to Alaskan or North Pacific waters.

The formation of feeding flocks brings a great many birds of several species into a small and localized area, increasing the possibility that environmental disruptions that are quite localized may nonetheless influence a large number of individuals and species that range over a much broader area. Further, as the food supplies that stimulate the formation of feeding flocks are locally concentrated, environmental alterations that reduce the birds' access to such food concentrations may lead to a breakdown of the feeding flock relationships or force foraging into other areas; both of these effects may have important consequences for marine bird populations.

Our functional analysis of flock organization and analysis of initiation cues indicate that significant interdependencies occur among species. Behavior and morphology act jointly to increase the efficiency of fish school exploitation by a mixed-species assemblage. The behavioral adaptations include highly developed responsiveness to behavioral cues indicating prey concentrations and interspecies manipulative behaviors resulting in a more efficient species organization within flocks, but apparently do not include food-finding calls. The most important morphological characters that act as flock-location cues are apparently plumage characters. Even small-scale fouling of plumage might well reduce the effectiveness of these cues in promoting flock formation, and thereby affect overall foraging success of a number of species.

Given the patterns of species interdependencies in feeding flocks, reduction in the numbers of kittiwakes (for example, by development of facilities near nesting cliffs) would have a potentially greater impact on the populations of jaegers and large alcids, and probably on the populations of cormorants. Reduction in the numbers of puffins or murres might adversely affect the kittiwake and gull populations, but this relation is less certain. A major reduction in shearwater numbers would probably not adversely affect the other species of birds, at least through its alterations of mixed-species flock composition, although such an impact on marine food chains might well be substantial. The impact of kittiwake population reduction on alcid populations would likely be greater in areas without extensive tidal rips, but would presumably be major in all areas.

APPENDIX I

SCIENTIFIC NAMES OF BIRD SPECIES

Common Name	Scientific Name
Common Loon	*Gavia immer*
Arctic Loon	*Gavia arctica*
Red-throated Loon	*Gavia stellata*
Black-footed Albatross	*Diomedea nigripes*
Fulmar	*Fulmarus glacialis*
New Zealand Shearwater	*Puffinus bulleri*
Sooty Shearwater	*Puffinus griseus*
Short-tailed Shearwater	*Puffinus tenuirostris*
Scaled Petrel	*Pterodroma inexpectata*
Fork-tailed Storm-Petrel	*Oceanodroma furcata*
Leach's Storm-Petrel	*Oceanodroma leucorhoa*
Double-crested Cormorant	*Phalacrocorax auritus*
Brandt's Cormorant	*Phalacrocorax penicillatus*
Pelagic Cormorant	*Phalacrocorax pelagicus*
Red-faced Cormorant	*Phalacrocorax urile*
Red Phalarope	*Phalaropus fulicarius*
Pomarine Jaeger	*Stercorarius pomarinus*
Parasitic Jaeger	*Stercorarius parasiticus*
Long-tailed Jaeger	*Stercorarius longicaudus*
Glaucous-winged Gull	*Larus glaucescens*
Western Gull	*Larus occidentalis*
Herring Gull	*Larus argentatus*
California Gull	*Larus californicus*

Mew Gull	*Larus canus*
Bonaparte's Gull	*Larus philadelphia*
Heermann's Gull	*Larus heermanni*
Black-legged Kittiwake	*Rissa tridactyla*
Red-legged Kittiwake	*Rissa brevirostris*
Sabine's Gull	*Xema sabini*
Arctic Tern	*Sterna paradisaea*
Aleutian Tern	*Sterna aleutica*
Common Murre	*Uria aalge*
Thick-billed Murre	*Uria lomvia*
Pigeon Guillemot	*Cepphus columba*
Marbled Murrelet	*Brachyramphus marmoratus*
Whiskered Auklet	*Aethia pygmaea*
Rhinoceros Auklet	*Cerorhinca monocerata*
Horned Puffin	*Fratercula corniculata*
Tufted Puffin	*Lunda cirrhata*

APPENDIX II

Feeding methods used in North Pacific Feeding Flocks

(All except those marked by [*] are from Ashmole 1971.)

Aerial Piracy.......One bird chases another in the air and attempts to rob it.

*Aerial Plunging.....Bird plunges from air for a fish near the surface.

Pursuit Plunging....Bird plunges from air and swims under water.

*Surface Plunging....Bird plunges from sitting position on surface; submerges most of its body.

*Hop Plunging........Bird sitting on surface jumps ~ 1 m into air, then plunges.

Pursuit Diving......Bird dives from surface, swims under water.

LITERATURE CITED

Anderson, D.R., J.L. Laake, B.R. Crain, & K.P. Burnham. 1976. Guidelines for line transect sampling of biological populations. Utah Cooperative Wildlife Research Unit, Utah State Univ., Logan. 27 pp.

Anderson, D.R., & R.S. Pospahala. 1970. Correction of bias in belt transect studies of immotile objects. J. Wildl. Mgmt. 34: 141-146.

Armstrong, E.A. 1946. The coloration of seabirds. Why does white plumage predominate? Birds of Britain 2: 15-19.

Ashmole, N.P. 1971. Seabird ecology and the marine environment. pp. 223-286 in Avian Biology, Vol. 1 (D.S. Farner & J.R. King, Eds.). New York, Academic Press.

Bailey, R.S., & W.R.P. Bourne. 1972. Notes on sea-birds 36: Counting birds at sea. Ardea 60: 124-127.

Brock, V.E., & R.H. Riffenburg. 1960. Fish schooling: A possible factor in reducing predation. J. Conseil. Int. Explor. Mer. 25: 307-317.

Brown, R.G.B., D.N. Nettleship, P. Germain, C.E. Tull, & T.Davis. 1975. Atlas of eastern Canadian seabirds. Canadian Wildl. Serv. Ottawa. 220 pp.

Burnham, K.P., & D.R. Anderson. 1976. Mathematical models for nonparametric inferences from line transect data. Biometrics 32: 325-336.

Caughley, G. 1974. Bias in aerial survey. J. Wildl. Mgmt. 38: 921-933.

Caughley, G., & J. Goddard. 1972. Improving the estimates from inaccurate censuses. J. Wildl. Mgmt. 36: 135-140.

Caughley, G., R. Sinclair, & D. Scott-Kemmis. 1976. Experiments in aerial survey. J. Wildl. Mgmt. 40: 290-300.

Clarke, T.A., A.O. Flechsig, and R.W. Grigg. 1967. Ecological studies during project Sealab II. Science 157: 1381-1389.

Darwin, C. 1890. The Descent of Man (2nd Ed.). London, Murray.

Eberhardt, L.L. 1968. A preliminary appraisal of line transects. J. Wildl. Mgmt. 32: 82-88.

Gates, C.E. 1969. Simulation study of estimators for the line transect sampling method. Biometrics 25: 317-328.

Gates, C.E., W.H. Marshall, & D.P. Olson. 1968. Line transect method of estimating grouse population densities. Biometrics 24: 135-145.

Gérard, G., & P. Berthet. 1971. Sampling strategy in censusing patchy populations. Pp. 59-68 in Statistical Ecology. Vol. 1. (G.P. Patil, E.C. Pielou, & W.E. Waters, Eds.). University Park, Penn. State Univ. Press.

Gould, P.J. 1971. Interactions of seabirds over the open ocean. Unpublished PhD. Dissertation, Tucson, Univ. Arizona.

Grant, P.R. 1971. Interactive behaviour of puffins (*Fratercula arctica* L.) and skuas (*Stercorarius parasiticus* L.). Behaviour 40:

Hayne, D.W. 1949. An examination of the strip census method for estimating animal populations. J. Wildl. Mgmt. 13: 145-157.

Hunter, J.R. 1969. Communication of velocity changes in Jack Mackerel (*Tuachurus symmerticus*) schools. Anim. Behav. 17: 507-514.

Järvinen, O., & R.A. Väisänen. 1975. Estimating relative densities of breeding birds by the line transect method. Oikos 26:316-322.

Joensen, A.H. 1972. Studies on oil pollution and seabirds in Denmark 1968-1971. Dan. Rev. Game Biol. 6(9): 1-32.

King, W. 1970. The Tradewind Zone Oceanography Pilot Study, Part VII. Seabird observations March 1964 to June 1965. U.D. Dept. Interior Spec. Sci. Rept. Fisheries 586: 1-227.

King, W. (Ed.) 1974. Pelagic studies of seabirds in the Central and Eastern Pacific Ocean. Smithsonian Contrib. Zool. 158: 1-227.

Kovner, J.L., & S.A. Patil. 1974. Properties of estimators of wildlife population density for the line transect method. Biometrics 30: 225-230.

Leopold, A. 1933. Game Management. New York, Scribners.

Marine Pollution Bulletin. 1970. Bird deaths mount in Alaska. Mar. Poll. Bull. 1(5): 66

Morse, D.H. 1970. Ecological aspects of some mixed-species foraging flocks of birds. Ecol. Monogr. 40: 119-168.

Murton, R.A. 1971. The significance of a specific search image in the feeding behaviour of the Wood-pigeon. Behaviour 40: 10-42.

Myrberget, S., & S.A. Strömme. 1974. The effect of terrain structures on population estimates found by King's method. Nor. J. Zool. 22: 273-277.

Nettleship, D.N. 1972. Breeding success of the Common Puffin (Fratercula

Overton, W.S. 1971. Estimating the numbers of animals in wildlife populations. Pp. 405-455 in Wildlife management techniques, (R.H. Giles, Jr., Ed.). Washington D.C., Wildlife Society.

Parr, A.E. 1927. A contribution to the theoretical analysis of the schooling behavior of fishes. Occ. Pap. Bingham Oceanogr. Collect. 1: 1-32.

Pielou, E.C. 1974. Population and community ecology. Gordon & Breach, New York.

Poole, R.W. 1974. An introduction to quantitative ecology. New York, McGraw-Hill.

Pulliam, H.R. 1973. On the advantages of flocking. J. Theor. Biol. 38: 419-422.

Reynolds, R.T., J.M. Scott, & R.A. Nussbaum. 1977. A variable circular plot method for censusing birds. Unpub. MS

Robinette, W.L., C.M. Loveless, & D.A. Jones. 1974. Field tests of strip census methods. J. Wildl. Mgmt. 38: 81-96.

Sanger, G.A. 1970. The seasonal distribution of some seabirds off Washington and Oregon with notes on their ecology and behavior. Condor 72: 339-357.

Sanger, G.A. 1972. Preliminary standing stock and biomass estimates of seabirds in the Subarctic Pacific Region. In Biological oceanography of the northern North Pacific Ocean. (W.Y. Takenouti, Ed.), Tokyo.

Sawatsky, H.L., & W.H. Lehn. 1976. The arctic mirage and the early North Atlantic. Science 192: 1300-1305.

Scott, J.M. 1973. Resource allocation in four syntopic species of marine diving birds. Unpublished Ph.D. Dissertation, Corvallis, Oregon State Univ.

Sealy, S.G. 1973. Interspecific feeding assemblages of marine birds off British Columbia. Auk 90: 796-802.

Sen, A.R., J. Tourigny, & G.E.J. Smith. 1974. On the line transect sampling method. Biometrics 30: 329-340.

Shaw, E. 1960. The development of schooling behavior in fishes. Physiol. Zool. 33: 79-86.

Shaw, E. 1961. The development of schooling behavior in fishes. Physiol. Zool. 34: 263-272.

Simmons, K.E.L. 1972. Some adaptive features of seabird plumage types (2 parts). Brit. Birds 65:465-479; 510-521.

Skellam, J.G. 1958. The mathematical foundations underlying the use of line transects in animal ecology. Biometrics 14: 385-400.

Tucker, V.A. 1974. Energetics of natural avian flight. Pp. 298-333 in Avian Energetics (R.A. Payneer, Jr. Ed.). Cambridge. Mass., Nuttall Ornithol. Club Publ. No. 15.

Vermeer, K., & G.G. Anweiler. 1975. Oil threat to aquatic birds along the Yukon coast. Wilson Bull. 87: 467-480.

Vine, I. 1973. Detection of prey flocks by predators. J.Theor. Biol. 40: 207-210.

Webb, W.L. 1942. Notes on a method of censusing snowshoe hare populations. J. Wildl. Mgmt. 6: 67-69.

Weller, G., & D.W. Norton. 1977. Oil in the Arctic. 2. The Outer Continental Shelf Environmental Assessment Program. Interdisp. Sci. Rev. 2: 215-226.

Wiens, J.A., & J.M. Scott. 1975. Model estimation of energy flow in Oregon coastal seabird populations. Condor 77: 439-452.

ORAL PRESENTATIONS

"The application of line transect theory to the density estimation of pelagic birds" Dennis Heinemann, American Ornithologists' Union Annual Meeting, Berkeley, California. August 1977

"Feeding flock initiation cues among Alaskan seabirds" Wayne Hoffman, American Ornithologists' Union Annual Meeting, Berkeley, California. August 1977

PAPERS IN PREPARATION FOR PUBLICATION (Authorship yet to be defined)

"Simulation studies of the effect of motion on the density estimation of birds by the line transect method"

"Density estimation of birds at sea"

"Age-dependent foraging success in Black-legged Kittiwakes"

"The composition and organization of mixed-species seabird feeding flocks"

"Seabird feeding flocks may be group-advantageous 'selfish herds'"

FINAL REPORT
RECONNAISSANCE OF THE INTERTIDAL
AND SHALLOW SUBTIDAL BIOTIC
LOWER COOK INLET

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RESEARCH UNIT 417

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JOB NO. 6797-004-20
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ABSTRACT

A reconnaissance survey of the intertidal and shallow subtidal habitats of lower Cook Inlet was conducted during May, June, July and August 1976. This survey comprised an aerial reconnaissance of the west side of the inlet and examination of several sites in representative habitats in the intertidal and shallow subtidal zones on both sides of the inlet. In all, reconnaissances were conducted in nine general sites on the east side of the inlet and in seven on the west.

Several geological facies are common in lower Cook Inlet. Mudflats prevail around the mouth of the Kasilof River. From above Clam Gulch to north of Anchor Point, the intertidal zone is dominated by unconsolidated beachs with gravel upper slopes and sand lower slopes. Between Anchor Point and the base of Homer Spit, the upper slopes continue to be gravelly, but the lower slopes become rocky with sand patches. The south side of Kachemak Bay and Kennedy Entrance are generally dominated by rock intertidal zones but gravel beaches are common. In contrast to the smooth shoreline north of Homer, this coastline is quite irregular and rugged; mudflats are found at the head of most of the embayments. The intertidal zone of the Barren Islands is also dominated by rock. On the west side of the inlet, sand beaches dominate the exposed coastline and extensive mudflats border the embayments. Additionally, gravel upper slopes and flat sandstone benches are important, the latter particularly in southern Kamishak Bay.

Species compositions and complexity of the biotas vary distinctly by substrate. Assemblages found in sand and mud habitats were quite similar on both sides of the inlet. The sand beach assemblages were dominated by polychaete worms (*Scolelepis* and *Nephtys*), haustoriid

amphipods and clams (Spisula and Siliqua). Mudflat assemblages were dominated by clams (Mya spp. and Macoma balthica), echiurid worms (Echiurus) and polychaete worms (Nephtys).

South of a line from Anchor Point to Chinitna, rocky intertidal zones on both sides of the inlet were generally visually dominated by seaweeds, but the algal assemblages differed between the two sides. The biotic assemblages on the east side of the inlet were generally more mature and complex than those observed on the west side. Generally, the floras of the mid-intertidal zones on both sides were dominated by red algae, including Rhodymenia palmata, Callophyllis spp., Halosaccion glandiforme,and on the east side, Odonthalia spp.; the brown alga Fucus distichus (rockweed) and Alaria spp. were also important mid-intertidal species south of Homer on the east side of the inlet. Lower intertidal levels were generally dominated by laminarian kelps, mainly Laminaria groenlandica, Alaria spp. and Hedophyllum sessile on the east side and L. groenlandica on the west side. Subtidal algal assemblages were much more diverse, robust and mature on the east side of the inlet. Based on previous work, it appears that bull and ribbon kelp (Nereocystis luetkeana and Alaria fistulosa) consistently form extensive beds with floating canopies out to a depth of about 12 m. in late spring and summer; L. groenlandica and Agarum cribrosum are visual dominants throughout the year out to at least 25 m. in many locations. On the west side, L. groenlandica and Alaria ?marginata were the dominant algal species; in sharp contrast to the situation observed on the east side, neither extends much below 3 m. and surface canopies were not observed.

The intertidal faunal assemblages were basically dominated by the same species, but their diversity, robustness and maturity differed dramatically. Some of the more common organisms were acorn barnacles, a sponge (Halichondria panicea), some limpet species, a periwinkle (Littorina sitkana), a mussel (Mytilus edulis), a starfish (Leptasterias hexactis), and a whelk (Nucella emarginata). Generally, the populations observed on the west side of the inlet comprised mainly juveniles; animals more than one year old were rare. Furthermore, those assemblages had comparatively low species diversity. It appears that winter conditions on the west side are sufficiently rigorous to severely restrict development of rocky intertidal populations and assemblages.

The subtidal faunal assemblages on the east and west sides differed to a great extent in species composition. Although both are strongly detritus-based assemblages, dominated by suspension feeders, the general appearance of the assemblages, and types of component species differed markedly. On the west side, the assemblages were heavily dominated by encrusters such as barnacles (Balanus rostratus alaskensis), encrusting and head-forming bryozoans (e.g., Bidenkapia spitsbergensis, Rhamphostomella sp., Costazia spp., and Parasmittina sp.) and sponges (e.g., Halichondria panicea and Mycale ?lingua). On the east side, the assemblages were dominated by a large mussel (Modiolus modiolus), sabellid and oweniid polychaete worms, clams (e.g., Saxidomus giganteus and Macoma spp.), arborescent bryozoans (e.g., Flustrella gigantea, Microporina borealis and Dendrobeania murrayana) and hydroids (Abietinaria spp. and Thuiaria spp.) Competition for space appeared intense on both sides, but biomass appeared much higher on the east side.

Predator assemblages appeared more highly developed on the east side of the inlet. The starfish fauna was represented by at least sixteen species on the east side of the inlet as compared with seven on the west. The same pattern seemed to hold true for other major predator groups such as fish, crabs and snails.

If the benthic assemblages of Cook Inlet are divided into export systems (producing more plant material (energy) than required to maintain their faunal assemblages) and import systems (producing less plant material than necessary to support their faunal assemblages and therefore importing plant material), an interesting and important pattern is observed. Export systems, typified by kelp beds, are generally restricted to outer Kachemak Bay, Kennedy Entrance and the Barren Islands, all in the southeast quadrant of lower Cook Inlet. The remaining portions of Cook Inlet are primarily import systems, as exemplified by beaches and mudflats. These require import of plant material from other locations to support their nutrient requirements. In view of the apparent standing crops of consumers in these habitats, the energy needs are substantial. The water circulation regime is certainly sufficiently dynamic to facilitate the transport of plant materials to import systems.

Plant material is available to marine systems in three major forms, namely, phytoplankton, macrophytes (marine grasses and seaweeds) and organic debris of terrestrial origin (mainly entrained in freshwater runoff). Phytoplankton production is strongly limited in time (about March through September), macrophyte production is strongly limited geographically, and contributions of terrestrial organic debris are limited both temporally and geographically. As a consequence of these patterns, we postulate that the three energy resources are roughly equally important to the maintenance of the faunal assemblages in lower Cook Inlet, but that macrophytes perform a special and very important function because they are the major food resource being produced during late fall and winter.

These apparent patterns in the distribution of import and export assemblages are important in understanding the inter-relationships of the Cook Inlet systems and should provide some very useful tools in planning resource management and petroleum development in lower Cook Inlet.

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	1	Base of Homer Spit
	2	Bishop's Beach
	3	Whiskey Gulch
	4	Deep Creek
	5	Clam Gulch
	6	Amakdedori Beach
	7	Chinitna Bay-Clam Beach
	8	Polly Creek

1.0 INTRODUCTION

Cook Inlet extends about 175 miles inland from the northwestern corner of the Gulf of Alaska to the mouth of the Susitna River (Figure 1). It is divided into the Upper and Lower Inlet by the Forelands. The lower inlet is geologically, oceanographically and biologically complex and the oceanography and biology of the area are poorly understood. Early in this century, a few biological expeditions entered Cook Inlet, (Fisher 1930), but the collections were few and the results are scattered and fragmented. Only in the past few years have programs been directed at understanding the inlet's oceanographical and biological systems.

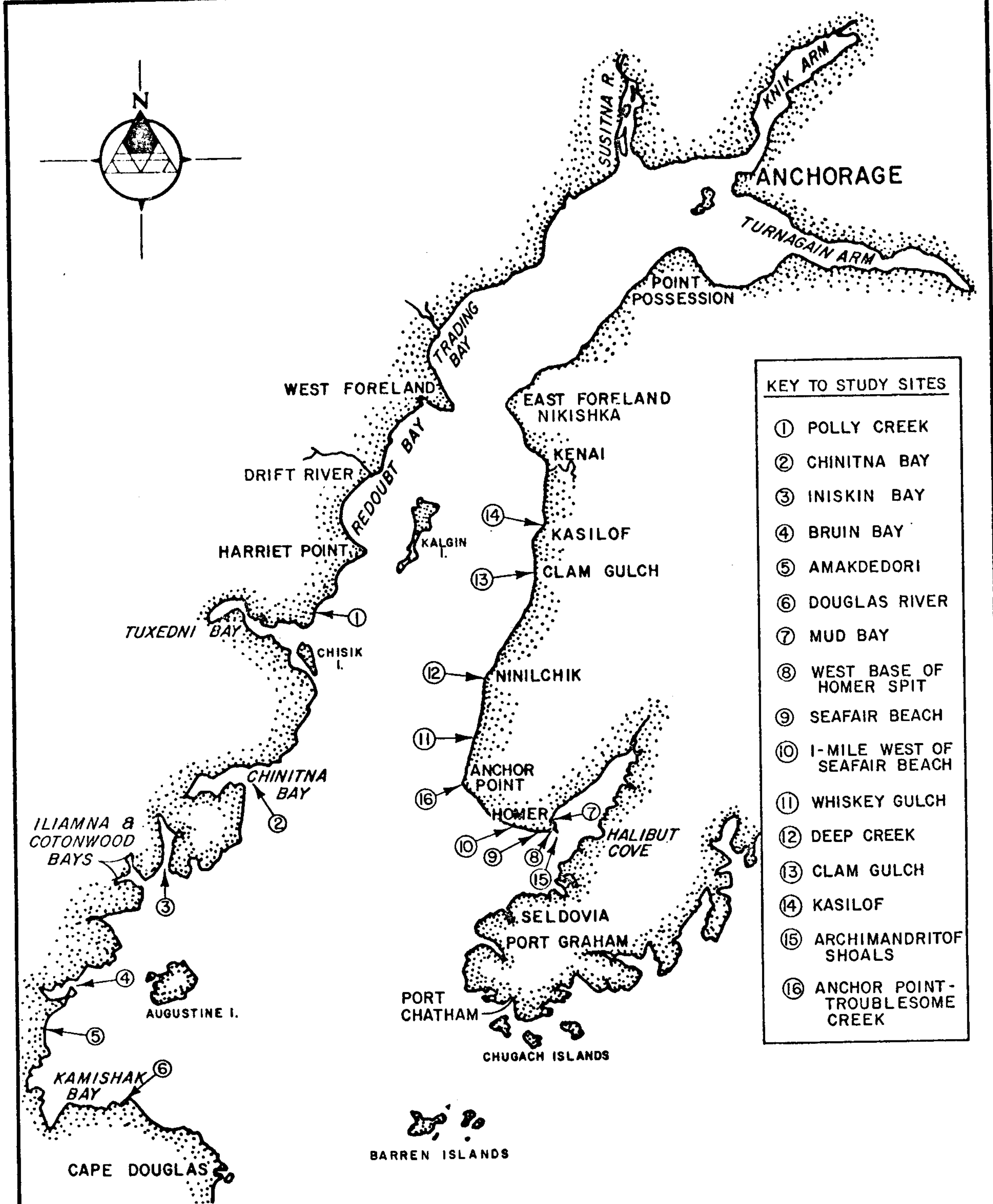
1.1 Objectives

In order to promote adequate planning and implementation of the forthcoming lease sales and potential offshore exploratory drilling, the Department of Interior has directed that appropriate research be conducted to increase the information available for agencies involved in decision making activities.

As a part of this effort, the objective of this study has been to conduct a reconnaissance of the habitats and biological assemblages in the intertidal areas of lower Cook Inlet. This has been accomplished by means of an aerial reconnaissance of the lower inlet to determine the distribution of coastal habitats, and a series of cursory intertidal surveys to determine the nature of the biological assemblages associated with the habitats observed. This report is a summary of our findings.

1.2 Study Sites

Selection of study sites was designed to permit examination of representative habitats and biological assemblages on both sides of lower Cook



SITE-LOCATION MAP

DAMES & MOORE

FIGURE 1

Inlet. General areas on the east side of the Inlet were Homer, the north shelf of Kachemak Bay, Whiskey Gulch, Deep Creek, Clam Gulch and the mouth of the Kasilof River. On the west side of the inlet, the general areas included the mouth of the Douglas River, Amakdedori Beach, Bruin Bay, Iniskin Bay, Chinitna Bay and Polly Creek. In all, eleven general areas were examined on the east side of the inlet and sixteen on the west.

1.3 Survey Periods

Intertidal survey work was conducted during four periods of extremely low tides. Most of the sites on the east side of the inlet were examined during a tide series extending from 12-17 May 1977. The aerial reconnaissance of the west side of the inlet, necessary for assessing and determining the areas to be visited, was conducted on 29 and 31 May. Most of the sites on the west side of the inlet were examined between 9-15 June. Additional sites were examined during the following month; this included two sites on the west side on 13 July and one site near Homer on 14 July.

Subtidal reconnaissances were conducted on 20 and 22 July and 3 August 1977 in Kachemak Bay and on 21 through 24 August on the west side of the inlet. The deterioration of summer weather patterns precluded completion of planned subtidal reconnaissance.

1.4 Participants

Personnel involved in the survey are listed by activity below:

a. Survey of the east side of the Inlet.
   1. Jon Houghton, Dames & Moore, Biologist;
   2. Dennis Lees, Dames & Moore, Biologist and Project Manager;
   3. Richard J. Rosenthal, Dames & Moore, Biologist;
   4. Thomas Rosenthal, Dames & Moore, Biologist.

b. Aerial reconnaissance.

1. Tina Cunning, ADF&G, Observer;
2. Dennis Lees, Dames & Moore, Biologist;
3. Richard Rosenthal, Dames & Moore, Biologist;
4. Thomas Rosenthal, Dames & Moore, Biologist.

c. Survey of the west side of the inlet.

1. Dennis Bishop, Dames & Moore, Technician;
2. Garvan Bucaria, BLM, Observer;
3. Jon Houghton, Dames & Moore, Biologist;
4. Dennis Lees, Dames & Moore, Biologist;
5. Richard J. Rosenthal, Dames & Moore, Biologist;
6. Thomas Rosenthal, Dames & Moore, Biologist.

Bill DeCreeft, owner and pilot of Kachemak Air Services, provided invaluable information and logistical support during the aerial reconnaissance and surveys of the west side of the inlet.

2.0 METHODS AND MATERIALS

2.1 Study Area Selection

Intertidal study areas were selected on the basis of characteristic substrate type, vulnerability to environmental disturbance and accessibility. Eleven areas were examined on the east shore of lower Cook Inlet and Kachemak Bay. Sixteen areas were examined on the west shore of the inlet and in Kamishak Bay (Figure 1). Several habitats were examined at some of these areas.

2.2 Procedures

Intertidal field work was accomplished during low tide periods in May, June and July 1976. Generally, each area was examined biologically only once only once during the study. Access to study areas on the east shore of Cook Inlet was by four-wheel drive vehicle. Access to areas on the west shore was by fixedwing aircraft landing on floats or wheels, as appropriate. An inflatable boat was used for additional mobility to some study areas on the west shore. During the field visits, major emphasis was placed on qualitative description of the study area and collection of representative specimens for each habitat for later identification. At least two Dames & Moore biologists were present for each survey.

Subtidal field work was accomplished during periods in July and August when tide exchanges were not great. Access to the area was accomplished on a charter vessel, the M.V. Humdinger. General procedures were quite similar to those utilized in the intertidal surveys, and accomplishments were generally the same. The major difference in methods was the utilization of 1 x 25 m or 0.5 x 25 m quadrats to determine abundance of large, important species.

The following were accomplished at each study area where feasible:

a. The general physical characteristics of the intertidal area were described.

b. Epiflora and epifauna were qualitatively described over the full tide range.

c. Quantitative measurements of organism densities, percent cover, etc., were made using radom 0.0625 (1/16), 0.25 or 1.0 sq. m. quadrat casts or line transects.

d. Organisms living on and among other organisms were sought out and described.

e. Unconsolidated substrates (gravel, sand, and mud) were excavated and examined for infauna.

f. Quantitative measurements of infaunal densities were made using haphazard casts of hand operated beach corers. Material from a large corer (30 cm. deep by 79 sq. cm.) was sieved through a 4-mesh Tyler screen (4.75 mm. openings). Material from a small corer (10 cm. deep by 44 sq. cm.) was sieved through a 20-mesh Tyler screen (0.85 mm. openings).

g. Organisms taken in the cores and other organisms of questionable identity were either preserved in the field or collected live and returned to the field laboratory in Anchor Point for identification.

h. Approximate beach profiles were surveyed where possible.

2.3 Taxonomy

As expected, many problems were encountered in attempting to identify organisms found in this study with standard taxonomic references for the northeast Pacific Ocean. Intertidal and shallow subtidal organisms of lower Cook Inlet have not been previously studied in a systematic way and few extensive collections from this area have been examined by taxonomists. Thus, many organisms were encountered with characters intermediate to or outside the ranges of variation considered definitive for separate species in standard keys. In some cases, it was possible to clear up these questions by reference to the original literature. In others, questions remain which must await a rigorous investigation by taxonomic specialists. Problematic individuals of some groups have been submitted to such specialists for examination. Some groups of minor ecological and economic importance that require extensive histological preparation and microsopic examination for positive identification (e.g. Nemertea) were not identified further. Thus, in the species lists accompanying this report (Appendix A, B, C and D) there are many organisms where identification was not pursued to the genus and species level and others where the identification as listed is considered questionable and is denoted with a question mark.

3.0 AERIAL SURVEY OF WESTERN LOWER COOK INLET

It was necessary to conduct an aerial reconnaissance of the Barren Islands and the west side of Lower Cook Inlet in order to determine the location of feasible study sites and assess the nature and distribution of the habitat types to be encountered. This recon was conducted in two stints on 29 and 31 May 1976. Observations were made from a Dehavilland Beaver (Kachemak Air Service) flying at elevations ranging from 1200 to 150 feet, depending upon turbulence conditions; air speed was approximately 80 knots. Data on habitat type, slope, biological cover, animal aggregations, type of vegetation and logistics were recorded. Important biological and geological facies were photographed.

3.1. Geological Structures

Six basic intertidal habitats were observed during the reconnaissance. These included 1) pavement or bedrock bench or reef, 2) boulder field, 3) gravel/cobble beach, 4) brown or gray sand beach, 5) sand/gravel flats and 6) mud flats. Generally the first three habitats were observed in both protected and exposed locations, the fourth in exposed situations and the last two in protected areas. Protected areas were observed in embayments and, in the southern portion of Kamishak Bay, behind offshore sandstone reefs and finger reefs.

Approximately 300 miles of coastline, including 80 miles of islands, were surveyed. Protected habitats, mainly 150 miles of shallow bays and estuaries, dominate the coastline, particularly on the mainland. This habitat type is characteristic of Sukoi Bay, southwest Kamishak Bay, Bruin Bay, Ursus Cove, the Iliamna-Cottonwood Bay system, Iniskin Bay, Chinitna Bay and Tuxedni Bay. Other protected areas are located in south Kamishak Bay behind and among the pavement reefs. On the mainland, sand beaches and rocky (rock, boulder or cobble) habitats were about equally represented by approximately 60 miles of each (about 30% of the coastline).

In some areas, it was necessary to record a portion of the shoreline under two categories. This was particularly true in Kamishak Bay, where the sandstone reef and bench structures imparted sufficient protection to allow the development of extensive mud flats between or behind them. This type of habitat was particularly abundant from just south of Douglas River to Nordyke Island.

The mainland shoreline is bordered by cliffs of varying elevations, by low hills, or by low dune-like structures. Although appearing ironbound in many locations, nowhere does the shoreline become precipitous; the cliffs are always bordered by a moderate to gently sloping beach of sand, gravel or cobble, or a rock bench. Greatest beach slope observed was on the coast between Oil Bay and Chinitna Bay.

Some of the habitats are rather locally distributed. The flat sandstone or pavement benches and reefs are generally restricted to southern Kamishak Bay and in the vicinity of Chisik Island. Boulder/ cobble field areas are mainly located between Cape Douglas and Kamishak Bay, along the northern shore of Augustine Island, between Oil Bay and Chinitna Bay, and from Spring Point (north corner of Chinitna Bay) to Silver Salmon Creek. Sand gravel beaches (gray and red/brown) are distributed generally along the west side of the inlet. The same is true for the larger bays.

Local variation in the structure of rocky outcrops and headlands is notable and the distribution of the variation is similar to the distribution described for rock benches and reefs and boulder fields. In south Kamishak Bay, outcrops and headlands are smooth, flat and rather rounded, with little loose material. Starting at about Iniskin Bay and extending to Tuxedni Channel, outcrops and headlands are much more irregular and rubble strewn. This will be discussed in more detail in the DISCUSSION section.

The main islands included in the study area are the Barren Islands, Mt. Augustine (an active volcano), and Chisik Island. Kalgin Island was excluded from the survey. The Barrens, in the entrance to Cook Inlet, are exceedingly exposed and so the geological structure of the beaches differs markedly from the others; 80% of the 40-mile coastline is rock. Ironbound coastline is commonplace, with the cliffs plunging into moderately deep water. Only about 50% of the coastline of the less exposed islands is rock, with the remainder divided among mud flats, sand or gravel beaches, and boulder fields.

3.2 Biological Assemblages

Only limited biological information can be obtained from aerial reconnaissance. Mainly only macrophyte assemblages can be recognized and our experience indicates that, without considerable ground truth information, even our general interpretations were of limited reliability.

Basically five types of macrophyte assemblages were recorded during the reconnaissance, namely, 1) large laminarians (*Alaria* spp., *Nereocystis luetkeana* and *Laminaria* spp.), 2) other brown algae, 3) red algae, 4) green algae, and 5) eelgrass (*Zostera marina*). The latter was strongly questioned during our subsequent discussions before ground truth studies and the consensus was that all green assemblages were green algae. That conclusion subsequently proved in error when ground truth was obtained.

With the exception of the laminarian assemblages, the various categories are based mainly on color, which leaves open a broad range of interpretation, and encourages some gross errors. The most risky were the green assemblages, which could indicate eelgrass, Ulothrix sp., Ulva or Monostroma spp., Spongomorpha sp., or, in one extensive area, a sun bleached red alga, Halosaccion glandiforme. The red assemblages mainly represented beds of Callophyllis sp., Rhodymenia palmata, Iridaea sp., Porphyra sp., or Halosaccion.

The non-laminarian brown assemblages indicated mainly rockweed (Fucus distichus) and the filamentous Pylaiella littoralis. Without on-site inspection, none of these assemblages except for large laminarians could be identified from the air.

Invertebrate populations or assemblages on rock were not detected during the survey. Ground truth indicated that barnacles were the only widespread group that should likely be observed from the air. Because of environmental conditions over much of the western side of the inlet, barnacle populations might have been sparse at the time of the aerial survey. However, during the ground truth examinations (one-half month later), barnacle spat literally masked much of the intertidal rocks. Silt retained on the shells masked the normal coloration of the barnacles and made them undetectable from even a short distance.

Aggregations of Steller sea lions, sea gulls, kittiwakes, cormorants and other sea birds were observed in several locations. Major sea lion rookeries were noted on rocks at the southwest tip of Ushagat Island, in the Barren Islands, and on the east side of Shaw Island, in southern Kamishak Bay. The pilot (Bill DeCreeft) reported another small rookery on the east side of Augustine Island. A small group of seals was observed around Gull Island, in Chinitna Bay and at Burr Point, Augustine Island. Several sea otters were observed on the southeast side of Augustine. Major seabird rookeries were observed on the southeast side of Nord Island, in the Barrens, and on the southeast point of Chisik Island, in Tuxedni Bay. Dense feeding aggregations of sea gulls were noted on the sandstone benches and reefs in southern Kamishak Bay.

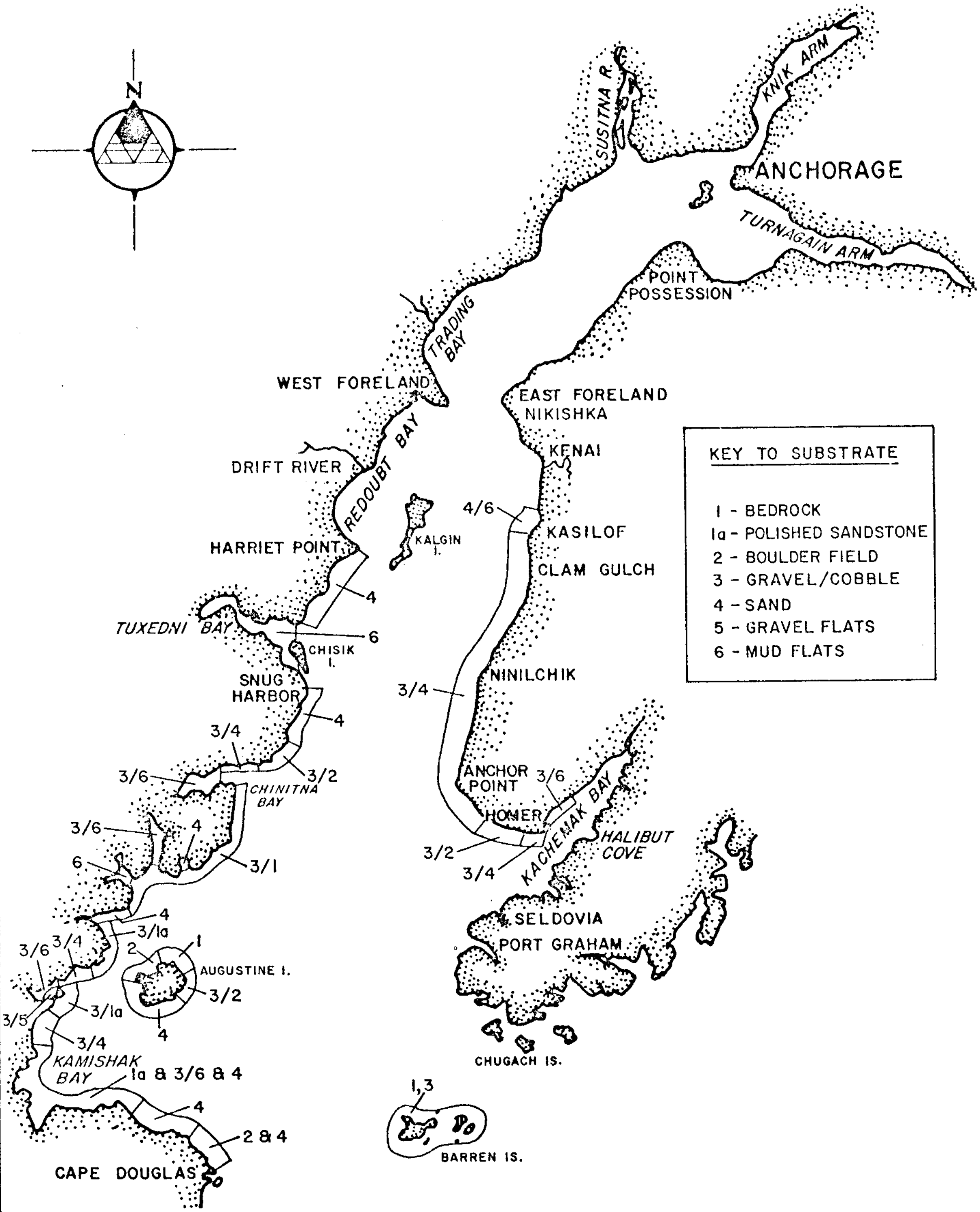
Shell debris was the main indication of important animal assemblages on soft substrates such as sand/gravel beaches or flats and mud flats. Abundant shell debris was observed on a few beaches along the south side of Kamishak Bay, south of the Douglas River, and at Polly Creek.

3.3. Distribution of Geological Structures and Biological Assemblages

The aerial survey commenced at the Barren Islands. Wind and turbulence conditions precluded observation from lower than 1,000 feet. Nord and Sugarloaf Islands are generally ironbound, except for a long reef on the south side of the latter. The intertidal area observed on them was quite narrow, of bedrock and boulders. Algae cover observed was sparse.

The northern side of Ushagat Island, largest of the Barrens, is mainly bordered by gravel beaches with scattered, jagged, rock outcrops. Beach slope is moderate. The outcrops had moderate cover of brown algae; offshore reefs supported a modest bed of *Alaria* sp. The bight on the west side is mainly cobble. Wave action was considerable and the water was turbid; however, offshore reefs supported both *Nereocystis* and *Alaria*. A large sea lion rookery was observed on the rocky reef projecting from the southwest point of the island; algal cover, mainly small browns, was moderate. In the bight between the SW point and the waist of the island, the gravel beach is bordered by high cliffs. Rock outcrops and reefs are common and supported moderate algal cover. Both *Alaria* and *Nereocystis* were common offshore. The waist was bordered by a long, sweeping, moderately sloping gravel beach with no offshore reefs or algae observed. The southeastern and eastern head is very rocky and steep and supported a moderately heavy brown algal cover. Offshore reefs are abundant.

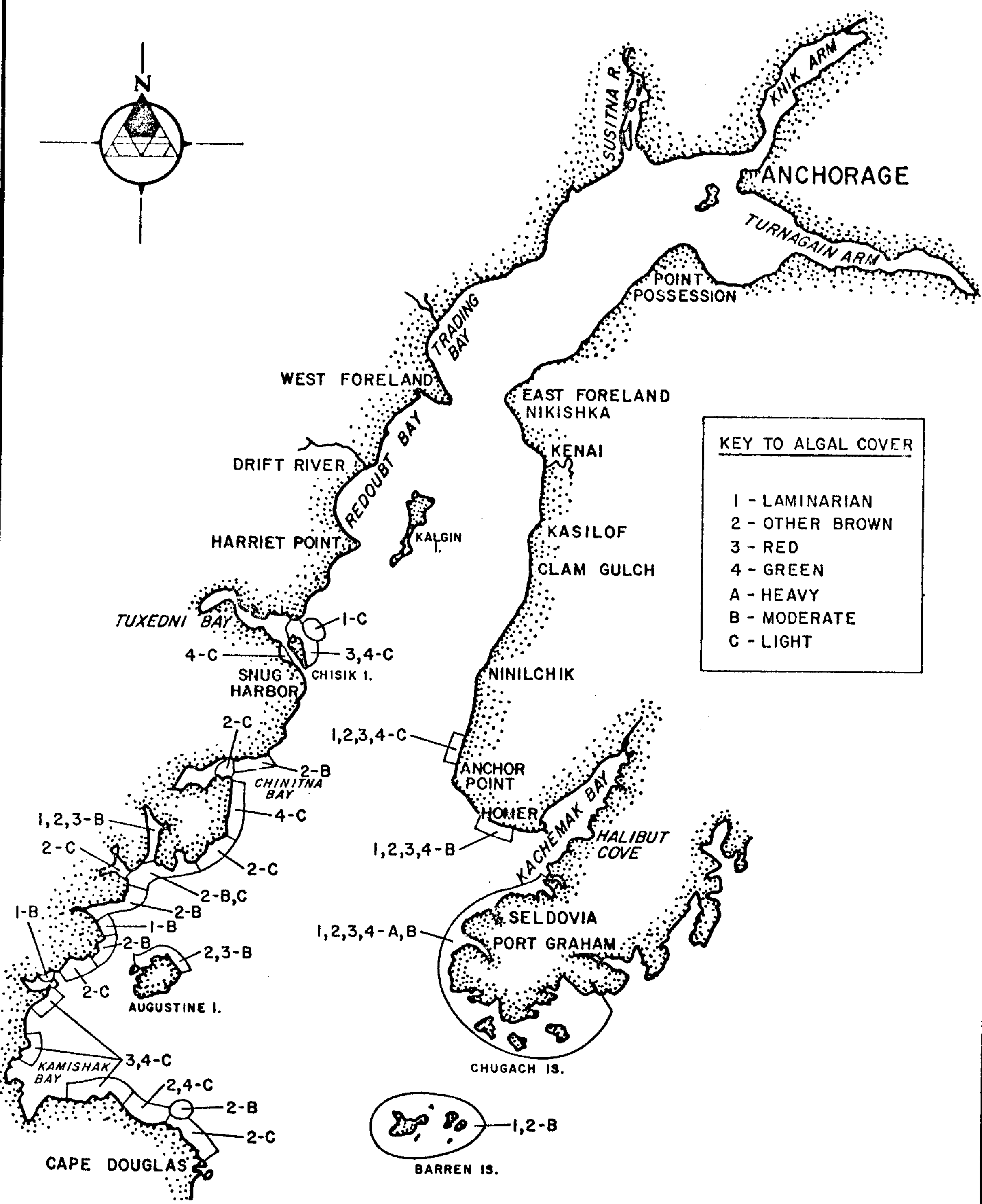
Sud Island is one of the smaller of the Barren Islands. The north and east sides of the island are mainly gently sloping gravel beach or



DISTRIBUTION OF GEOLOGICAL SUBSTRATE TYPES AS INDICATED BY AERIAL RECONNAISSANCE IN MAY 1976

DAMES & MOORE

FIGURE 2



DISTRIBUTION OF THE TYPE & DENSITY OF ALGAL COVER AS INDICATED BY AERIAL RECONNAISSANCE SURVEYS IN MAY 1976

DAMES & MOORE

FIGURE 3

boulders on bedrock with scattered outcrops. It has the most extensive intertidal area in the group and the offshore reef system is substantial. Algal cover by brown algae was moderate; Alaria grew on the offshore reefs. The south and west sides are rockier and steeper with apparently heavy brown algal cover.

East and West Amatuli Islands are both predominantly very precipitous or ironbound. The west side of W. Amatuli is ironbound and supported moderate algal cover. A large cove with a moderately sloping gravel beach indents the north side. The northeast side is ironbound; moderate brown algal cover was observed on the intertidal rocks and Alaria was observed offshore. In the southern bight, forming the passage between the two islands, the beaches are moderately sloping gravel and cobble. A protected cove on the north side of E. Amatuli is the main break in its predominantly ironbound shoreline.

Fierce tide rips were observed south of Nord Island and at the southwest tip of Ushagat Island. The wind was blowing eastward at about 40 knots at the time.

Because of extreme air turbulence, it was unfeasible to approach within less than about 3 miles of Cape Douglas and Sukoi Bay. The pilot (Bill DeCreeft) indicated that the head of Sukoi Bay is sandy, but that the entrance is rocky; he recalled having seen kelp growing in the area. Very little algal cover was apparent at this time. Snow still covered the ground down to the beaches over much of the southern Bay area.

Between Sukoi Bay and Shaw Island, the shore was mainly bordered by high cliffs. The shoreline was mainly long smooth stretches of gravel interrupted by rock outcrops. Brown algae formed a light cover on much of the intertidal rock.

Shaw Island is low, flat and barren. Bedrock is exposed and extends into the water on all sides. It forms an extensive intertidal bench on the west, and supported a moderate cover of brown algae. No kelps were observed. The lower limit of the brown algal belt was shallow and evident from the air. A moderate sized sea lion rookery was located on the eastern point.

The southern shorelines of Kamishak have a rather monotonous appearance. Extending from Shaw Island to just south of Douglas River are two long stretches of flat red sand beach with shoals oriented normally to the coastline. Shell debris was heavy in certain areas. The few rock outcrops and small headlands appeared to support a light brown algal cover. Just south of the Douglas River, the shoreline is dominated by a smooth, polished, broad sandstone bench. This type of structure extends west to Akumwarvik Bay, at the mouth of Kamishak River, and north to past Chenik Head. Occasional boulder piles are scattered on the bench. Interspersed among the various benches and offshore reefs are extensive mud flats. The expanse of littoral zone exposed on a very low tide is quite impressive. Mixed red and green algal cover was very light; ground truth examination in this habitat indicates that the dominant algae may have been the reds *Porphyra* or *Halosaccion* and the greens ?*Monostroma*, *Ulva*, *Spongomorpha*, *Ulothrix*; the green may also have been eelgrass (*Zostera marina*). In scattered locations, sea gulls were dense.

Several large slabs of sandstones, higher than the bench, are scattered around southern Kamishak like so many huge flagstones. Nordyke Island is the largest of these. Each, surrounded by an extensive sandstone bench, seems to support sparse terrestrial vegetation and a sizable sea gull population. Probably several other bird species, such as puffins and cormorants, may nest on these structures.

From Chenik Head to Contact Point, outside of Bruin Bay, the shore is a gently sloping sand and gravel beach with scattered rock outcrops. Above the drift line the shore is heavily covered with stranded timber. The rock outcrops were nearly devoid of algal cover, but the quantity increased a little on finger reefs extending from the shore under Contact Point.

Bruin Bay appeared to be a large, bare mud flat with numerous boulders scattered around. Deeper water is located on the northeast portion of the bay and the main channel separates the north and south portions. The northeastern portion is quite rocky; the rocks extend above the spray zone, support terrestrial vegetation and act as nesting grounds for many marine birds. Laminarians were observed on rocks on the north side of the bay, but the only vegetation on the mud flats appeared to be a diatom film.

Our observations at Bruin Bay did not produce an accurate description of biological or geological conditions. In fact, a large portion of the area reported as mud flat is gravel. Furthermore, the flat area supported a considerable standing crop of Laminaria spp., other red, green and brown algae, and an extensive area is covered by eelgrass. We believe that the eelgrass was largely absent from the flats during the aerial recon, however. This will be discussed in greater detail below.

The shoreline between Bruin Bay and Rocky Cove is mainly gently sloping sand with numerous offshore reefs which supported a moderate algal cover. Rocky Cove has mainly a pavement-like reef and an offshore reef, both of which supported moderate algal cover.

Algal cover on the reefs southeast of the mouth of Ursus Cove varied greatly from absent to moderate laminarian cover. The shore is a beach with scatteered rocky outcrops. The shoreline is backed up by high cliffs.

The head of Ursus Cove is a sandy beach and appeared to support some eelgrass; the inner portion of the cove is also sandy and is purported to support eelgrass. The north side of the bay is a gentle sand beach with some gravel and scattered offshore reefs that supported a light algal cover.

The shoreline of northern Kamishak Bay between Ursus Cove and Chinitna Point is generally a gravel beach below high cliffs. Occasional rock outcrops, reefs and small islands provide a moderate amount of hard substrate intertidally and subtidally. Algal cover graded from moderate near Ursus Cove, Iliamna, Cottonwood and Iniskin Bays to slight or absent at Chinitna Point. Subtidal algae seemed to disappear between Dry Bay and Chinitna Point. Intertidal algal cover was reduced to a green film in the high intertidal at Chinitna Point.

There is a strong resemblance between the biological and geological characteristics of Cottonwood, Iliamna, and Iniskin Bays. The intertidal zones are predominantly silty mud flats of various sizes. Cottonwood Bay has boulders scattered across the flats. Iniskin Bay finger reefs and rock outcrops along its eastern shore.

Diatom films, algae and possibly eelgrass were observed commonly in each of these bays. The algal cover appeared to mainly consist of *Laminaria* and *Alaria*, and was mainly located on the western or northern sides of the bays.

The flats in Iniskin Bay are quite extensive. A green algal cover was located in small pockets on the flats. On the east side of the bay, the shore was steeper and rockier and the pavement reefs supported a moderate brown and a red algal cover, mainly *Laminaria groenlandica* and *Rhodymenia palmata*. The beaches are mainly sand and gravel with large areas of sandstone bench.

A group of islands extends offshore from the entrance of Iniskin Bay almost to Oil Bay. These are bedrock with gravel and bedrock beaches and supported light to moderate algal cover. Several islands extend above the spray zone and supported terrestrial vegetation. Seabirds and seals utilize them for rookeries and haulouts.

Oil Bay is similar to the other bays in the presence of algal cover on its west shore; the green cover may have been eelgrass. The broad beach at the head of the bay is of gently sloping red sand and is said by fishermen to support a dense population of large razor clams.

Augustine Island dominates much of the seascape in Kamishak Bay and contributes about 40 miles of coastline. Generally, the island slopes gently to the beach. Low cliffs on the east-facing shore attest to the erosive conditions in lower Cook Inlet. Beaches on the southeast, east and northeast sides of the island are predominantly sand with varying quantities quantities of scattered boulders and some outcrops. Offshore reefs are common. Seaweeds were not apparent on the southeast beaches, but a light algal cover was seen on boulders on the eastern beaches and laminarians were present on reefs off the northeast beaches. Beaches on the north and northwest are also sand with scattered boulders and sand with offshore reefs; rock is more common there. Northern beaches in the vicinity of Burr Point also supported moderate cover of laminarians and other brown algae. Reefs in this area are well developed. Northwestern beaches had a moderate cover of red and brown algae. The beach on the west is mixed sand and bare scattered boulders. The southwestern and southern beaches appear to be fine clean sand, sloping moderately. On the western side of the island is a large lagoon with mainly rocky borders. The borders appear bare except in the western entrance, which appears to support a light algal cover of laminarians.

The island shores are utilized by several species of marine mammals and birds. Harbor seals were sighted in the lagoon and near spawning herring schools at Burr Point. Sea otters were observed fishing and feeding just outside of the surf on the sandy southwestern and southern beaches, suggesting that those areas support clams or crabs. Sea gulls were observed all around the island, but were particularly concentrated near Burr Point. A small sea lion rookery is reported for the southeastern side of the island.

From Chinitna Point to about Gull Island, in Chinitna Bay, the beach is moderately sloping gravel and quite narrow. The scattered boulders were devoid of algal cover. The coastline is precipitous with beaches lying at the base of low cliffs.

Gull Island in Chinitna Bay, is geologically varied. On the north side is located a small cove with a moderately steep sand beach. The sides of the cove are steep bedrock and boulders. A cobble/boulder field slopes onto a bedrock bench on the west side. The eastern side is a combination of the flat sandstone bench, finger reefs and boulders. Sparse algal cover was observed on the east and west sides. Harbor seals and several sea bird species were observed around or on the island.

Bounded by steep hills and cliffs, the eastern three miles of the southern shore of Chinitna Bay are bedrock with a veneer of cobble; finger reefs are common. The rocks had a light brown algal cover. As the adjacent slope becomes flatter, it changes progressively from sand and gravel to mud. The western end of the bay is bordered all around by broad mud flats. The only surface relief is traced by drainage channels. The only algal cover appeared to be a surface film of diatoms on the higher mud flats. At Glacier Spit, on the north shore, the upper beach becomes moderately sloping gravel but the lower mud flats continue eastward for an additional several miles. The gravel upper beach continues out to about Spring Point. The lower mud flat gives way to sand, which supported dense populations of the razor clam *Siliqua patla*. A rock outcrop interrupts the gravel beaches on the south shore at Clam Cove. Apparently connected to this is a large offshore reef. The rocks in this area supported a moderate cover of brown algae, including *Alaria*.

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Spring Point is a broad bedrock bench covered with boulders. The boulder fields and complex reef systems supported a moderate algal cover, but laminarians were not observed. North of Spring Point, the shore is broken into sweeping stretches of sand and gravel by small rock outcrops. Large boulders are scattered throughout the offshore area, creating a considerable hazard to nearshore navigation. The rocks in this area were bare.

From the vicinity of the Red River mouth to the entrance of Tuxedni Channel, the shore is dominated by flat, broad beaches of brown sand and gravel. The same type of beach is present from just north of Tuxedni Bay past Polly Creek to at least Harriet Point, the northern extent of the aerial survey. The northeastern corner of Tuxedni Bay is of similar material, but the currents have thrown the sand into a series of large waves forming broad intertidal shoals at the southern end of Polly Creek Beach. Some pavement reefs supporting a light cover of brown algae and *Alaria* are scattered within the channel between the shoals and Chisik Island. The brown sand beaches are known to support vast razor clam populations.

The south shore of Tuxedni Channel is a narrow boulder field with occasional rock outcrops; rocks were devoid of algal cover. To the west, the bench broadens and becomes muddier; drainage channels crossing the gently sloping mud flat supported a light cover of green algae. The bench is quite broad where it gives way to Fossil Point, a large rock outcrop with large polished finger reefs. West of Fossil Point are very broad mud flats that border Tuxedni Bay for many miles. The north side of Tuxedni Bay is similar, except the mud gradually gives way to brown sand in the vicinity of Chisik Island.

On Chisik Island, a national seabird refuge, the shoreline is nearly evenly divided between soft substrate and rock. The southwest side of Chisik Island, bordering Tuxedni Channel, is a rather narrow, moderately sloping bench extending from the Snug Harbor Cannery to near the western tip of the island. The western tip of the island is a broad flat muddy shelf. The north side is considerably rockier; several offshore reefs with a light cover of red and green algae were observed. The east end of the island is a sand/boulder beach with finger reefs and a small amount of the polished sandstone reefs. This area supported a light cover of seaweed, but no laminarians.

3.4 Turbidity Patterns

Several recurring patterns related to water clarity were noted during the aerial reconnaissance. In most areas surveyed, clearer water was located in the northern or western portion of a specific site. Northern Kamishak Bay, for instance, was much clearer than southern Kamishak. Furthermore, the north sides of the smaller bays were generally clearer. Also, the north side of Augustine Island had clearer water than the southern beaches. Algal distribution generally appeared to directly reflect the clarity patterns observed, but the observations, in turn, could have been affected by the degree of turbidity. Iniskin Bay was an exception to this pattern; both the east and west sides of the bay were clear during the reconnaissance, and algal cover and subsequent visits indicate that condition may be common.

4.0 GENERAL BIOLOGICAL CHARACTERISTICS (by habitat)

In this section the general characteristics of the intertidal and shallow subtidal benthic communities in lower Cook Inlet are described by habitat. This approach is akin to averaging qualitative descriptions of biota encountered on similar substrata and at similar tidal levels at various locations about the inlet. These descriptions can thus be extrapolated, with some reservations, to other geographic locations not examined about the inlet and might thus be used as a basis for predicting or assessing general impacts of environmental perturbations on those areas. Caution is required in using such extrapolations, however, because in all likelihood no specific location will exactly match the generalized description.

Variations in a myriad of physical environmental factors (e.g., salinity, turbidity, currents, wave and ice exposure, insolation, or exact substrate composition) and biological factors (e.g., competition, predation, or recruitment) affect the realized distribution and abundance of each organism at each specific location. More detailed descriptions of each area visited in this study are given in Section 5.0 and Appendices A and B.

Each habitat is considered by general tide level as follows:

a. Upper intertidal - roughly that area above Mean Sea Level (MSL);

b. Middle intertidal - that area from MSL to Mean Lower Low Water (MLLW); and

c. Lower intertidal - that area from MLLW to Extreme Low Water (ELW).

4.1 Rocky Habitat

This designation includes beaches of solid rock, boulders and large cobble, where the substrate is stable under all but the most severe surf conditions. Lower Cook Inlet rocky intertidal areas contain few species that are of direct economic value to man. They are important however as feeding areas for several fish and as producers of organic detritus and planktonic gametes and larvae that enter other marine food webs. Some important marine mammals such as the harbor seal (*Phoca vitulina*) and the sea otter (*Enhydra lutris*) and several bird species rest and feed in these areas. King crab (*Paralithodes kamtschatica*) spend a portion of their early life under boulders and among algae on low intertidal rocky areas. Several important fish species (e.g., salmonids and halibut) forage in such areas when submerged.

In addition to environmental factors such as salinity, temperature, insolation, turbidity and wave action which affect all intertidal habitats in somewhat similar ways, a factor that plays a major role in determining the character of many rocky intertidal communities in lower Cook Inlet is the grinding and abrading action by ice and, to a lesser degree, by logs. This abrasion removes sessile organisms from affected areas and, if it recurrs annually, results in simple communities of annuals and "pioneer" species with new recruitment each spring. Adjacent protected crevices and under rock areas tend to have a more diverse biota including many species typical of undisturbed rocky beaches.

4.1.1 Upper Intertidal

Upper intertidal rock in lower Cook Inlet is generally colonized by only a few types of very hardy organisms. In the splash zone above the high water line, the black lichen (*Verrucaria*) and other more colorful lichens (*Caloplaca*) may be found. The uppermost intertidal macroorganisms are acorn barnacles (*Balanus glandula*), limpets (*Notoacmea ?scutum* and *N. persona*), and periwinkles (*Littorina sitkana*). These snails first appear in shaded areas and in moist crevices from whence they venture to graze on microscopic algae.

At somewhat lower tide levels, these species become more abundant and widespread. They are joined by several other animals including the smaller barnacle (*Chthamalus dalli*), the limpet (*Collisella ?pelta*), and the blue mussel (*Mytilus edulis*).

Under large boulders in the upper intertidal, pill bugs (*Gnorimosphaeroma oregonensis*) and the amphipod (*Anisogammarus ?pugettensis*) may occur in profusion.

4.1.2 Middle Intertidal

Middle intertidal rocky areas in lower Cook Inlet are characterized by the presence of macroalgae (primarily *Fucus distichus*, *Scytosiphon lomentaria* and *Spongomorpha*) and the predatory snail (*Nucella emarginata*). Most of the organisms present below the splash zone in the upper intertidal reach their greatest densities in the middle intertidal zone where they are joined by several other important species. *Nucella* is a major predator on smaller barnacles and mussels and is instrumental in reducing the coverage of these organisms. This cleared space is thus available for colonization by other organisms. The larger barnacle *B. cariosus* is occasionally abundant, especially in protected areas and *B. crenatus* may replace *B. glandula* near MLLW. An isopod *Idothea fewkesi* may be present on *Fucus* fronds. Polychaetes may be present among the barnacles (*Eteone* nr. *longa*) or in silty crevices (*Cirratulus cirratus*).

Under rocks the amphipod *A. ?confervicolus* may join its congener *A. ?pgettensis* along with hermit crabs (*Pagurus*), the crescent gunnel (*Pholis laeta*), and other miscellaneous fauna. Encrusting sponges (*Halichondria panicea* and *Haliclona permollis*) are often present, on and under rocks and on the shells of barnacles.

4.1.3 Lower Intertidal

Lower intertidal rocky areas typically support the richest and most diverse epiflora and epifauna of any intertidal substrate. Rocky areas in lower Cook Inlet generally follow this pattern. Beginning near MLLW numerous species occur which are not present at higher levels. Competition and predation are intensified. The filter feeding *B. glandula* and *M. edulis* that dominate the middle intertidal rocks are largely replaced by species better equipped to withstand predation by a variety of starfish (*Evasterias* and *Leptasterias*) and gastropods (*Nucella*, *Neptunea* and *Fusitriton*). Also, macroherbivores may become important.

Predation, as well as abrasion by ice and logs, provides space for growth of a myriad of forms including algae and encrusting filter feeders, including a diverse assemblage of hydroids (e.g., *Abietinaria*), polychaetes (e.g., *Serpulidae Sabellidae*), bivalves (e.g., *Mya truncata*, *Hiatella arctica*), sponges (e.g., *Haliclona*, *Halichondria*), barnacles (e.g., *B. rostratus*, *B. nubilus*), Bryozoa (*Alcyonidium*) and tunicates (e.g., *Aplidium* and *Distaplia*).

In some areas such as Spring Point at Chinitna Bay, algae appear to dominate lower intertidal rock. Cover may be near 100% and include a profusion of red algae such as *Rhodymenia palmata*, *Iridaea* and the coralline algae, large brown algae such as *Alaria* and *Laminaria*, and some smaller greens such as *Cladophora*. In such areas, animals may be small and difficult to find beneath the algal mat. In other low rocky areas, such as west of Seafair Beach, Homer, algae have a less dominant role. This is often due to grazing by the sea urchin, *Strongylocentrotus drobachiensis*. Here the fauna is more obvious and abundant.

4.1.4 Shallow Subtidal

Rocky habitats appear to be spread in shallow subtidal areas fairly widely around lower Cook Inlet. However, the biotic assemblages inhabiting them vary substantially from site to site. This variation is particularly notable when comparing sites in Kennedy Entrance and Kachemak, which support lush algal assemblages, with sites located north of Anchor Point or on the west side of the inlet, where seaweeds are very sparse or absent. Visual comparisons are quite striking, and a comparison of algal standing crop and primary production would probably be equally dramatic.

In the shallow subtidal habitats, the greatest contributors to algal standing crop are generally the brown seaweeds. In Kachemak Bay and Kennedy

Entrance, the dominant species include Alaria fistulosa, Laminaria groenlandica, Agarum cribrosum and Nereocystis luetkeana. Seaweed production is considerable to deeper than 20 in. below MLLW. North of Anchor Point, on the east side of the inlet, and on the west side of the inlet, dominant species include Laminaria groenlandica, Alaria ?marginata and Desmarestia ligulata. Seaweed production becomes negligible at about -3 m below MLLW.

Epifaunal invertebrate assemblages in these same areas also differ considerably between the east and the west sides of the inlet. This is particularly apparent in the amount of barnacle and sponge cover, but the composition of the bryozoan, hydroid and starfish faunas are also quite distinct. Major species important in most areas include the barnacle Balanus rostratus alaskanus, the sponge Halichondria ?panicea, the mat-forming tubicolous polychaetes Potamilla spp., the snails Neptunea lyrata and Fusitriton oregonensis, a large mussel Modiolus modiolus, a flesh erect bryozoan Flustrella gigantea, the hermit crabs Elassochirus gilli and E. tenuimanus, the decorator crab Pugettia gracilis, a sea urchin Strongylocentrotus drobachiensis and the starfish Leptasterias polaris var. acervata, Crossaster papposus and Henricia sanguinolenta.

In Kachemak Bay, additional important species include the sea stars Evasterias troschellii, Pycnopodia helianthoides, Dermasterias imbricata, the butter clam Saxidomus giganteus, and a bryozoan Microporiua borealis. On the west side of the inlet, the most notable additional species are the bryozoans Bidenkapia spitsbergensis, Costazia ventricosa, and Terminoflustra membranaceo-truncata. Generally, however, the fauna on the west side is characterized by a suite of species rather similar to that described for the seafloor off Point Barrow by MacGinitie (1953).

4.2 Sandy Habitat

This designation includes beaches where the predominant substrate is sand, silty sand, or sand with small gravel. However, there are important ecological differences between these types of "sandy" beaches.

Coarser materials and lower quantities of fine silts and clays occur in areas of higher energy, that is, areas with high wave and/or current action. Such beaches are porous and drain rapidly, reducing their suitability for organisms sensitive to drying. Sediments on these beaches are generally unstable and thus a poor habitat for sessile or slow moving forms. The lack of fines and organic debris and the associated paucity of food material also reduces faunal diversity by eliminating most deposit feeders and many suspension feeders.

In lower energy situations, increasingly quantities of fine materials are present and the beaches tend to be more stable and moist. These factors encourage an increasing abudance and diversity of infauna. However, beaches with extremely high quantities of silt and clay are often unsuitable habitats because suspended sediments clog gills.

4.2.1 Upper Intertidal

Upper intertidal sandy beaches are largely devoid of macroorganisms (greater than 1.0 mm.). Several flies (Diptera) and beach hoppers *Orchestia* sp. may be abundant in drift algae at the high tide line.

4.2.2. Middle Intertidal

The middle intertidal range on the sandy beaches of lower Cook Inlet is also largely devoid of macrofauna. Near MLLW some infauna may be present, especially in siltier areas. Deposit feeding polychaetes such as *Nephtys*, and gammarid amphipods such as lysianassids, phoxocephalids and haustoriids may be common, although they are not as abundant as at lower levels.

4.2.3. Lower Intertidal

Lower intertidal sandy beaches in lower Cook Inlet often support substantial populations of commercially and recreationally important clam species such as the large filter feeding razor clam (*Siliqua* spp.) and redneck clams (*Spisula polynyma*). Other valuable species found here include tanner crab (*Chionocetes bairdi*) and sand lance (*Ammodytes hexapterus*), an important forage fish for salmonids, other fish, and many seabirds.

Smaller infauna include those types present in the lower portion of the middle intertidal as well as several additional polychaetes such as spionids (*Spio*, *Scolelepis*) and orbiniids (*Scoloplos*). Several other bivalves, mostly tellinids such as *Tellina lutea* and *Macoma* spp. are also found in low intertidal sands.

Typically the silt content of sandy beaches increases with increasing depth below MLLW and may, in less exposed areas such as Clam Gulch, approach the mud condition described below.

4.2.4. Shallow Subtidal

Shallow sandy subtidal assemblages have only been observed at a few locations in south central Alaska, and at none during this study. Koyuktolik Bay, in Kennedy Entrance, was characterized by a maldanid polychaete worm, a small clam (*Tellina nuculoides*), a sand dollar (*Echinarachnius parma*) and the sunstar *Pycnopodia helianthoides*. An olive shell (*Olivella baetica*) was also common (Dames & Moore 1977). Macleod Harbor, on Montague Island in Prince William Sound differed in that the sand dollar was replaced by a large sea pen *Ptilosarcus gurneyi* (personal observation). However, in deeper areas, it appears that such differences can be attributed to local patchiness and the patches of these species overlap broadly (personal observation).

4.3 Muddy Habitat

Muddy beaches occur throughout lower Cook Inlet in areas where waves and current action are insufficient to resuspend and remove silts and finer materials that settle from the water column or erode from adjacent shorelines. Much of these materials is of glacial origin and so is very fine. Muddy sediments therefore often have poor circulation, resulting in an anaerobic layer within a few centimeters of the surface.

Mud beaches frequently support high densities of soft shelled clams (*Mya* spp.), an edible species that is widely used for food in other parts of the world. In some areas eelgrass (*Zostera marina*) forms extensive beds and provides a suitable environment for many species, food for several species of ducks and geese, as well as organic debris for offshore food webs.

4.3.1 Upper Intertidal

Muddy substrates occur above MSL only in the most protected locations, such as at the heads of bays, and where the silt load is excessive such as near river mouths. Soft shelled clams, the small pink clam *Macoma balthica*, the lugworm *Abarenicola pacifica* may be abundant.

4.3.2 Middle Intertidal

Mud is fairly common in the middle intertidal of many of the bays of lower Cook Inlet. Most species occurring above MSL in mud reach their highest densities at these lower tide levels where they are joined by additional polychaetes (e.g., *Nephtys* nr. *caeca*), the burrowing "spoon worm" (*Echiurus*

echiurus alaskanus) and nemerteans (Paranemertes, Cerebratulus). Some eelgrass may also be present along with several other algae either attached to bits of debris or lying on the mud surface (e.g., ?Monostroma, Pylaiella). The burrowing anemone, Anthopleura artemisia is often present, especially in sandier muds and areas with some buried gravel.

4.3.3 Lower Intertidal

Good water retention by mud allows many organisms to survive over a wide tidal range. Therefore, lower intertidal mudflats have many species in common with middle intertidal mudflats. Generally all groups present exhibit increased diversity. The cockle (Clinocardium spp.) may join Mya spp. as the codominant large organisms and several species of polychaetes and Crustacea are usually present.

4.3.4. Shallow Subtidal

Several shallow subtidal muddy habitats have been examined in lower Cook Inlet, but the variation in composition is great enough that a typical biota cannot be determined. In all cases, the areas examined were estuarine. In some cases, the flora was dominated by eelgrass (Zostera marina) but in others by Laminaria saccharina or L. groenlandica. Generally, the fauna was dominated by clams and starfish, but the species involved ranged from Saxidomus giganteus, Tresus capax, Macoma spp. and Clinocardium nuttallii, Evasterias troschelii and Asterias amurensis, at Sadie Cove in Kachemak Bay, to Mya spp., Macoma balthica and leptasterias polaris var. acervata in Iniskin Bay.

Various crustaceans appear to be seasonally important. These include dungeness (Cancer magister) and helmet (Telmessus cheiragonus) crabs and a hermit crab (Pagurus ochotensis) (Dames & Moore 1976a). The two large crabs move into the shallow areas mainly in the summer.

Infauna on mixed-fine beaches typically includes many species found on muddy bottoms at similar tide levels but includes others more often found in silty gravel. Two clams of economic importance, the butter clam, *Saxidomus giganteus*, and the littleneck, *Protothaca staminea*, are among these species. Other bivalves, polychaetes, and amphipods are present along with burrowing cucumbers (*Chiridota*), sipunculids (*Golfingia*) and nemerteans (e.g., *Cerebratulus*). The diversity of infauna in mixed-fine habitats often exceeds that of any other habitat at comparable tide levels.

5.0 SPECIFIC DISTRIBUTION PATTERNS

This section contains a detailed description of the physical and biological characteristics of each area visited in the study. The narrative account of each area compares the area to the "typical" habitats (Section 4.0) emphasizing unique ecological conditions. The narrative is supplemented with an appendix table listing, by approximate tide level, all species found at the area, with a qualitative indication of abundance and significant ecological notes about the species.

5.1 East Shore Study Areas

Study sites on the east side of lower Cook Inlet were examined from Mud Bay, at the base of Homer Spit, in Kachemak Bay, to the delta at the mouth of the Kasilof River. Outside of Kachemak Bay, the eastern side of the Inlet exhibited little habitat diversity. A great deal of the difference between stations is undoubtedly due to the increased stress encountered by organisms at progressively northerly sites on this side. Stress is primarily a consequence of increasing silt loading in the water and sediments, and to the increasingly harsh ice conditions.

4.4 Mixed Habitats

Mixed habitats include those such as gravel and small cobble with varying amounts of fines that do not fall strictly into the above three categories. Mixed habitats may include characteristic species from one or more of the three basic habitats. Two mixed habitats of interest are "mixed-coarse" and "mixed-fine", which are distinguished by the amount of fine materials included in the sediments.

4.4.1 Mixed-Coarse Habitats

Mixed-coarse beaches consist of gravel and small cobble with some coarse sand but very little silt or clayey material. They typically occur at middle and upper tide levels where wave energy is high. Movement of the substrate by wave action prevents establishment of significant biota except where larger cobble is present. A biota similar to that at the same tide level is nearby rocky areas may become established in such situations.

4.4.2 Mixed-Fine Habitats

Mixed-fine beaches occur where silts are deposited on beaches with a higher content of gravel or small cobble. Such beaches occur at middle and lower tidal levels often well up into bays along lower Cook Inlet where gravel and cobbles are supplied by cliff erosion and silts are supplied by turbid stream runoff.

Where rocks or cobbles emerge from mixed-fine beaches, the epifauna and algae often resembles that on rock beaches at similar tide levels except that organisms intolerant of high silt deposition rates may be absent.

Although not examined during this portion of the study, personal observations on the southern Kenai Peninsula indicate that that area is more rich, diverse and complex than any other area in the lower Cook Inlet.

5.1.1.1. Homer Spit (Mud Bay)

Date: 7/14/76 Tide: -3.3 feet at 1020

Location: East of wooded island on east side of Homer Spit, about 1.5 miles out on spit

Mud Bay is located at the eastern juncture of Homer Spit and the north side of Kachemak Bay; it is protected location (Figure 1). Homer Spit originated as a glacial moraine and is therefore largely composed of gravel and cobble. Because Mud Bay is a protected habitat, fines have settled in the area, filling the interstices between the rocks and consolidating the substrate, Consequently, the area has greater water holding capacity and can provide more food than a pure gravel area.

The upper intertidal area has a moderate slope composed of well consolidated silt and large gravel. Several shallow channels are oriented perpendicular to the shoreline and carry runoff throughout the low tide. These channels provided suitable habitat for the brown algae Chorda filum and Scytosiphon lomentaria, which frequently covered up to 80% of the substrate. On the drier, high areas between the channels, algae were sparse, and the barnacle Balanus glandula and the soft shell clams Mya spp. were the dominant forms.

At about +2 feet, the slope levels out to form several relatively flat benches. These areas were also dominated by barnacles and Mya, and the blue mussel became important. Small clumps of this animal were nested deeply in the substrate. Density of Mya sp. and relative cover by mussels, indicated in Appendix A-1a, are 4.8 individuals per sq. m. and 3.5% cover, respectively. The lugworm Abarenicola pacifica, with densities approaching 300/sq. m., is very important in areas with surface water.

At about +2 feet the substrate becomes flatter and silt forms a soft, sticky veneer over the layer of gravel. The thickness of this silt veneer increases with distance below MLLW.

Below +2 feet density of the lugworm decreased dramatically and Laminaria saccharina, eelgrass (Zostera marina), and the spoonworm Echiurus echiurus alaskanus appeared. A green alga, Enteromorpha ?tubulosa became very abundant, covering about 75% of the substrate. Although present, eelgrass was sparse and generally the plants were young. Small clumps of large blue mussels were scattered around the mudflats in moderate quantities; individuals up to 10 cm. long were common.

Boulders up to 4 feet in diameter are scattered sparsely over the mudflat. Diversity was low on these rocks, but the species represented there were quite successful. These included Fucus distichus, Porphyra sp., Balanus glandula, Littorina sitkana and Mytilus edulis, all of which are quite tolerant species (Appendix A-1).

Moderate quantities of broken clam shells on and around these few boulders revealed an interesting facet of mudflat biology; by dropping bivalves on rocks to break their shells, seagulls use the rocks to increase the efficiency of their predatory activities on mussels and clams.

The energy pathways in this area are not unexpected. Plants, while important, do not directly contribute greatly to the local system. Primary consumers, particularly macroherbivores, were not observed in the area. Both suspension feeders (Balanus, Mytilus and Mya) and deposit feeders

(Macoma, Abarenicola and Echiurus) are important secondary consumers, depending largely on reworked organic material. It therefore appears that most of the primary productivity is exported. However, the amount of energy imported to feed the deposit feeders and suspension feeders is probably fairly close to the amount exported.

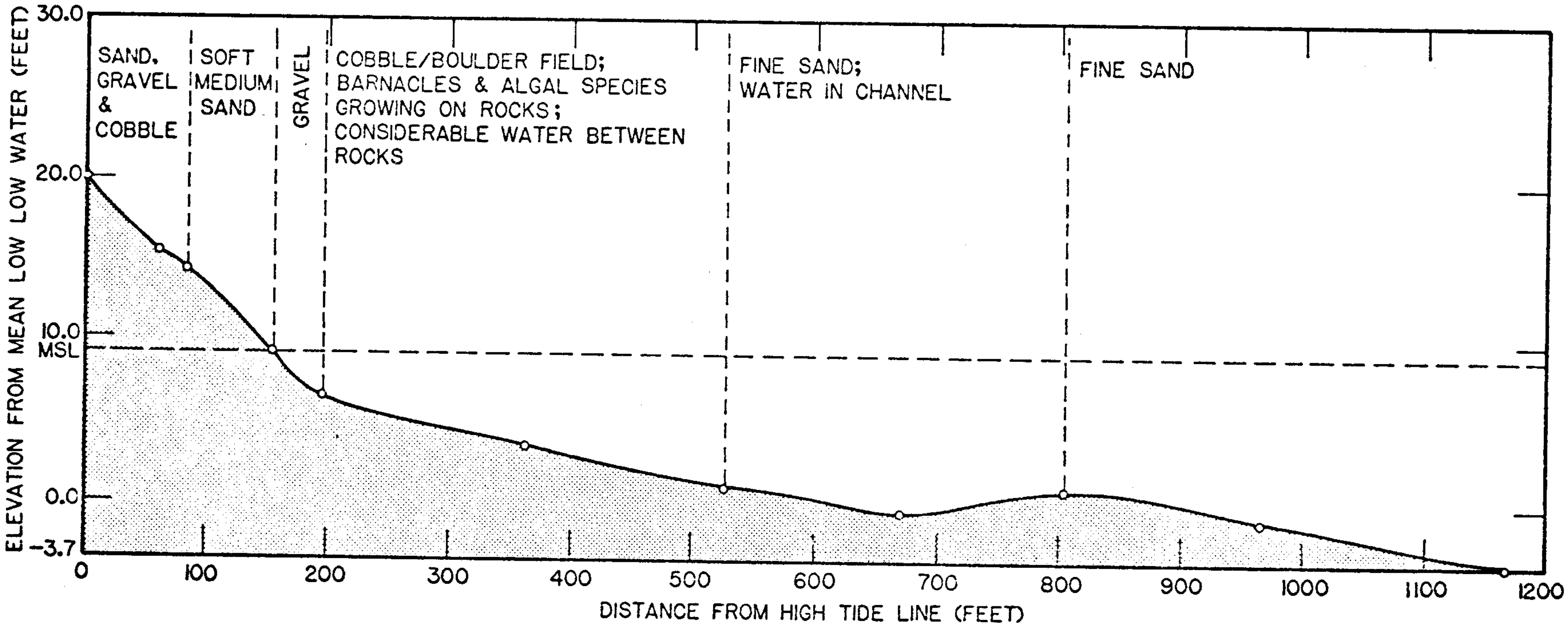
5.1.1.2 Homer Spit

Date: 5/13/76 Tide: -5.2 feet at 0748
Location: Base of Homer Spit, west side

On the west side of Homer Spit, near the base, sand and gravel dunes separate the beach from the highway (Figure 1). Above MHW a narrow sloping band of clean sand borders the dunes; a bit lower on the beach the sand gives way to a narrow band of gravel and coarse sand. Below this gravel band lies another narrow band of loose sand. No organisms were found in any of these strata (Figure 4). A moderate amount of drift material was observed at the high tide line.

Below the lower sand band, the beach slope decreases and the substrate changes to a more stable cobble and gravel shield (mixed-coarse) with a thin covering of glacial silt. Algae, mainly sieve kelp (Agarum cribrosam) and rockweed (Fucus distichus), were sparse. This broad stratum had a good under rock fauna with pile worms (Nereis vexillosa) and amphipods (Anisogammarus ?confervicolus, A. ?pugettensis) abundant. Present in lesser numbers were other polychaetes and amphipods. The lower edge of the cobble shield is at or below MLLW where the slope decreases further and the substrata changes back to sand.

In the relatively clean sand just below the cobble are the relatively sparse infauna included a few cumaceans, haustoriids, and small clam worms (Nephtys); no organisms were collected in six 44 sq.cm cores. At



BEACH PROFILE FROM BASE AT HOMER SPIT

JULY 1976

DAMES & MOORE

FIGURE 4

lower tidal levels (down to -4 ft), silt content increased and the infauna became increasingly abundant and diverse. This fauna was typical in many respects but included some species not found elsewhere, for example the tubicolous spionid *Spiophanes bombyx* and several bivalves including *Macoma* spp. The clam *Zirphaea pilsbryi*, which typically bores into soft rock, was unexpectedly found in relatively unconsolidated clayey sand. Redneck clams, cockles, and many sand lances were also present (Appendix A-2).

In terms of energy balance, this system appears to be largely an import system, although macroalgae in the cobble zone and microalgae in the sandy areas probably contribute somewhat in the summer months when photosynthetic rates are high.

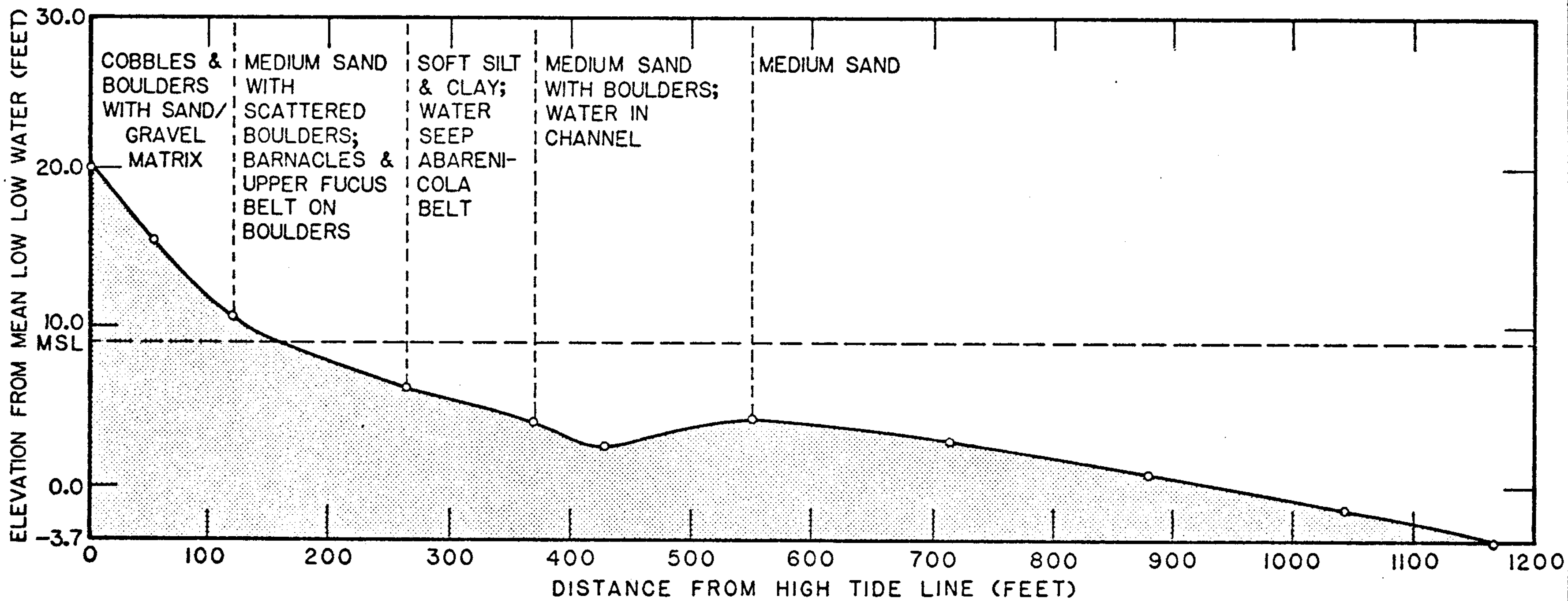
5.1.2 Bishops Beach

Date: 5/13/76 Tide: -5.2 at 0748

Location: Off Seafair Motel, Homer

From the base of the cliff at about EHW the upper beach off the Seafair Motel at Homer (Figure 1) consists of steeply sloping cobble and gravel; no macroorganisms found there. Below this area the slope decreases and the substrate changes to finer materials (sand and silt) for the remainder of the intertidal area (Figure 5). A moderate quantity of drift material was observed at the high tide line.

The upper portion of this sandy beach undulates in places to form shallow tide pools maintained by seepage from the upper beach. A high percentage of clayey material is present here and the lugworm (*Abarenicola pacifica*) is abundant. Random tosses of 0.073 sq. m. circular quadrat produced counts of from 1 to 20 castings per sample (Table 1); estimated density was 127 individuals per sq. m. An amphipod (*Anonyx* sp. A) was also present in these sediments along with the burrowing anemone *Anthoplera artemisia*. No macroorganisms were found on or in the slightly higher and much drier and less silty sand seaward of these seepage areas.



BEACH PROFILE FROM SEAFAIR BEACH

JULY 1976

DAMES & MOORE

FIGURE 5

Table 1. Density data for the lugworm _Abarenicola pacifica_ near MSL at Seafair Beach, 5/13/76

Number of per quadrat*		Number of quadrats
1		1
2		1
3		2
4		1
5		2
6		1
7		4
8		3
9		2
10		4
11		4
12		4
13		1
14		2
15		0
16		1
17		0
18		1
19		0
20		1
	Total	35
	$\bar{x} \pm s$	9.3 ± 4.3 individuals/quadrat

Estimated density - 127.6/sq. m.

*Circular quadrat enclosing 0.073 sq. m.

On lower beach, from about -3 ft to -5 ft, densities and diversity of macrofauna increased. The most abundant bivalve was the redneck clam. The razor clam (Siliqua alta) and Tellina lutea were also present though not particularly abundant. Large clam worms (Nephtys nr. caeca) were abundant along with several smaller polychaetes (Spiophanes bombyx, Magelona sacculata) and burrowing amphipods (Appendix A-3).

The fauna was strongly dominated by suspension feeders. In the absence of algae, the system is almost totally dependent upon import of food materials.

5.1.3 Bluff Point Area, west of Bishops Beach

Date: 5/15/76 Tide: -5.7 feet at 0919
Location: 1 mile west of Bishops Beach, Homer

The beach between "Seafair Beach" and Diamond Gulch (Figure 1) is largely comprised of gently sloping cobble and boulders throughout the intertidal range. Some extensive sandy areas are present, mostly below MLLW.

The upper beach, at the base of the bluff (about +15 ft) is almost entirely boulder and cobble with some limited areas of coarse gravel and a typically sparse biota. A recent heavy set of young barnacles, some unmetamorphosed, was evident of all exposures of rock in this area. It is expected that those in exposed areas will suffer complete mortality. Amphipods (Anisogammarus ?pugettensis) and pillbugs (Gnorimosphaeroma pugettensis) were abundant under rocks in this upper beach.

Further down the beach, these and other typical organisms became increasingly abundant on larger boulders in the vicinity of MSL. A dense cover of Fucus was evident, shading a typical faunal community of the barnacles, B. glandula and C. dalli, periwinkles (Littorina sitkana), limpets and small mussels.

Smaller boulders in this area were covered with the filamentous green alga Ulothrix sp. and had little epifauna, possibly because of siltation or scouring. Between boulders in this area, the substrate was a very silty sand; the burrowing anemone, Anthopleura artemisia was abundant. A lugworm was also abundant in some silty areas.

Still farther down the beach, near MLLW, larger boulders had dense growths of exceeding large barnacles (B. cariosus) and mussels (M. edulis). A typical barnacle measured 65 mm. in height and 45 mm. in basal diameter, while a typical mussel was about 80 mm. in shell length. Where B. cariosus had been knocked from the rock by ice or log abrasion, the smaller barnacle C. dalli had settled densely to take advantage of the space. A yellow sponge (Halichondria panicea) was also abundant on the shaded sides of rocks in the area.

Below MLLW, the beach extends in a broad undulating bench of exposed cobble and boulders interspersed with tide pools. There are also several large areas of clean sand with an infauna typical of other sandy beaches at this tide level; razor clams were reasonably abundant here.

The boulder and tide pool bench from MLLW to -5.5 feet supported the richest and most diverse biota of any intertidal areas examined north of Homer on the east side of Cook Inlet. Whereas the upper intertidal epiflora and fauna can be said to be limited primarily by physical factors (e.g., substrate, exposure, abrasion), the flora and fauna of this lower rocky bench appear to be limited by both biological factors (competition and predation) and physical factors (mainly turbidity).

Competition for "primary" space on the rocks and boulders was strong between plants such as encrusting coralline algae, fleshy red algae, and the brown alga, sessile animals like the encrusting sponges (Halichondria, Haliclona), bryozoans, polychaetes, cnidarians (Gersemia rubriformis and

Tealia crassicornis), and barnacles (B. glandula, B. crenatus, B. nubilus and B. rostratus). Small mussels were present where the tops of boulders offered some refuge from predators. The filter feeding "feather duster worm", Schizobranchia insignis, formed dense mats of intertwining branched tubes over areas of relatively flat cobble. These tube mats collected sand grains to form a reasonably stable substrate for several burrowing polychaetes (Glycera capitata, Pectinaria granulata, Nereis pelagica) and the nestling clam, Hiatella arctica. Several other tubicolous polychaetes were also present either entwined with S. insignis or separately in crevices between rocks.

The boring clam (Z. pilsbryi), the soft shelled clam Mya ?arenaria, littlenecks (Protothaca staminea) and butter clams (Saxidomus giganteus) were also present in and among the rock and cobble substrate.

Larger predators, both herbivores and carnivores, were highly evident. The most abundant large herbivore was the green sea urchin, Strongylocentrotus drobachiensis feeding mostly on bits of macro-algae; it averaged 13.2 individuals per sq. m. The small average size (Table 2; Appendix A-4a) and the size distribution suggest that the morality rate is high and/or that food is rather limited. Limpets (Notoacmea ?scutum) and chitons (Mopalia ciliata, M. lignosa, and Tonicella lineata) were abundant grazers of periphyton.

The major carnivores were several species of starfish (Evasterias troschelii, Pycnopodia helianthoides, Asterias amurensis and Leptasterias polaris) that prey mostly on mollusks and barnacles. The carnivorous anemones, Anthopleura artemesia, Tealia crassicornis, and a large yellow unid. species were also common. One of the latter had consumed a small sea urchin. The large gastropods (Neptunea lirata and Fusitriton oregonensis), that prey primarily on bivalves, were also present. Smaller carnivores and scavengers included the hermit crabs (Elassochirus gilli and Pagurus spp.), polychaetes (e.g., Eunoe) and several species of amphipods.

Table 2. Size distribution for <u>Stronglyocentrotus</u> spp on low bench, 1 mile W. of Seafair Beach, 5/15/76

Test Diameter (mm)	Frequency	Percent
5-9	1	1.2
10-14	7	8.1
15-19	4	4.7
20-24	13	15.1
25-29	14	16.3
30-34	30	34.9
35-39	13	15.1
40-44	2	2.3
45-49	2	2.3
50-54	1	1.2

Total 86

$\bar{x}$* 28.4 mm.

s 8.5 mm.

* $\bar{x}$ and s computed from unclassed data in Appendix A-4a

In addition to species already mentioned, the tide pools contained a variety of shrimp (Crangon alaskensis and C. stylirostris), mysids, a few fish (the tom cod, Microgadus proximus and a flatfish Pleuronectiformes), decorator crabs (Oregonia gracilis), and a white rudibranch (Dendronotus sp.).

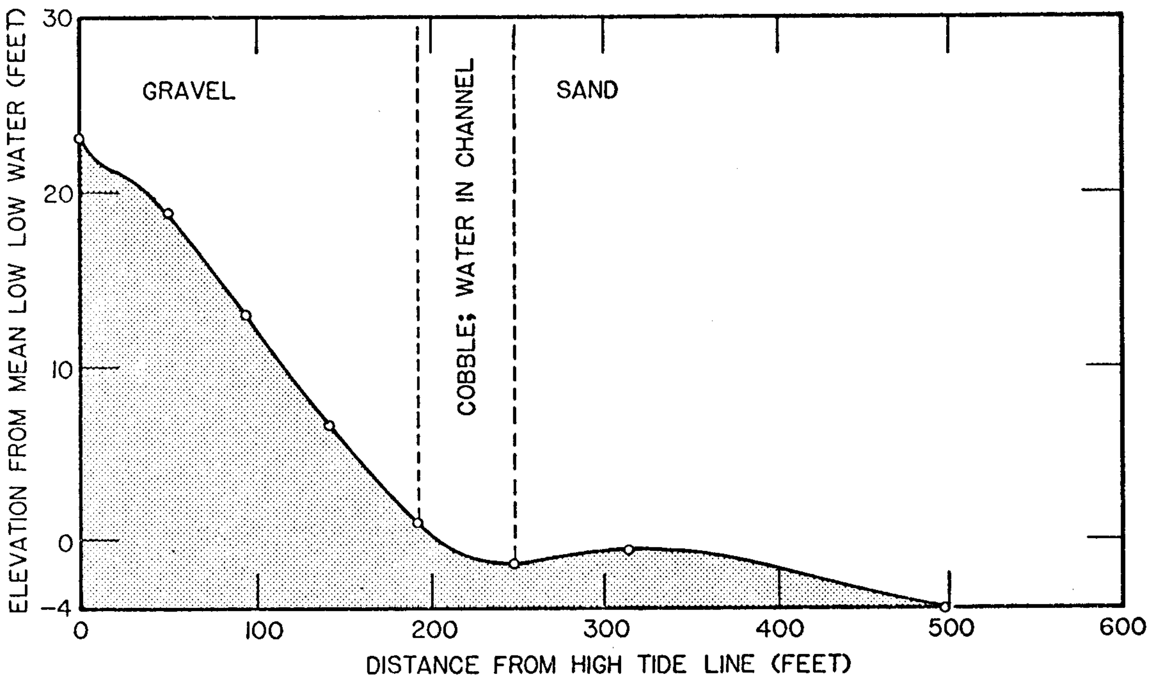
Trophic dynamics in this area were complex. The herbivorous sea urchins, chitons and limpets were quite common. The algal assemblage did not have a high standing crop, and so the herbivores might be consuming an appreciable portion of the primary productivity. Suspension feeders were extremely abundant and dominated the biotic assemblage. A broad variety of predators, mainly starfish, was present, utilizing both herbivores and suspension feeders. It is probable that the system is predominantly an import system, based on the abundance of suspension feeders.

Marine bird life observed included several gulls (Larus spp.), arctic terns (Sterna paradisaea) and two semipalmated plovers (Charadrius semipalmatus) (Appendix A-4).

5.1.4 Whiskey Gulch

Date: 5/12/76 Tide: 3.8 feet at 0700
Location: 1 to 2 miles south of Whiskey Gulch Road

A sand and cobble berm at about the extreme high water (EHW) level separates the beach at Whiskey Gulch from a bench of dunes, stagnant pools and alder scrub at the base of the bluffs (Figure 1). The seaward face of this berm is composed largely of clean sand extending below MHW. The slope of the sand is rather steep and is continuous with the slope of the broader band of loose gravel and coarse sand (mixed-coarse) which dominates the beach above MLLW (Figure 6). Apart from some small beach flies (Diptera) associated with drift algae at the high tide line, no macrofauna was found in either of these two substrata. Drift material was common at the high tide line.



BEACH PROFILE FROM WHISKEY GULCH
JULY 1976

DAMES & MOORE

FIGURE 6

At about MLLW the slope of the beach flattens considerably and the substrate changes to cobble and small boulders set in some finer material. Seep water coming out of the porous upper beach creates many small pools and rivulets and provides continuous wetting of the under boulder habitat.

Amphipods, primarily *Anisogammarus ?pugettensis*, were extremely abundant under rocks and in pools, with an estimated hundred or more under virtually every rock larger than 10-15 cm. in diameter. A large pink amphipod *Ampelisca eschrichtii* was common, often floating on the water surface in pools.

In a large tide pool at the lower edge of the boulder zone we found a large cottid (~20 cm. long), a hermit crab (*Pagurus ochotensis*) and a fleshy colonial bryozoan (*Alcyonidium pedunculatum*). A few large boulders (to several meters diameter) in this area had a rather typical fauna dominated by mussels (*Mytilus edulis*) and barnacles (*Balanus glandula* and *B. crenatus*). A fairly rich algal assemblage, dominated by *Polysiphonia ?pacifica*, was associated with the boulders.

Below the narrow cobble and boulder band the beach slope decreases further. The substrate changes to sand with increasing amounts of finer silts, perhaps of glacial origin, at lower tide levels. This broad silty sand beach probably continues below extreme low water.

Because of the unstable nature of this sand area no epifauna was observed although moderate numbers of amphipods (*A. ?pugettensis* and *Ampelisca eschrichtii*) were present in surface runoff water originating in the cobble band above.

Infaunal abundance in this sand area was typical and tended to increase at lower levels with increasing silt content of the substrate.

Fossorial amphipods dominated the smaller infauna. Typical sand burrowing polychaetes were also abundant.

Larger infauna included Nephtys nr ciliata and the burrowing orbiniid Scoloplos armiger. The lugworm (Abarenicola pacifica) was common in particularly silty areas with densities of casts averaging about 2.5 per sq. m.

Large bivalves species included the "redneck" clam (Spisula polynyma), the razor clam (Siliqua patula) and Macoma expansa. On the day of our visit to Whiskey Gulch, the tide was not low enough to permit sampling in areas of abundant razor clams reportedly found below -4 ft. The few recreational diggers present had gathered only a few clams apiece.

The horse crab (Telmessus cheiragonus) was found partially buried in the sand below -3 ft. Pacific sand lances (Ammodytes hexapterus) were abundant (more than 1/sq. m.) buried in the sand where surface runoff or wave wash kept the surface moist (Appendix A-5).

Several species of large brown algae were common growing on buried cobbles below -3 ft. These included adults and juveniles of Alaria sp. and Laminaria saccharina and adults of Desmarestia viridis and L. groenlandica.

In view of the paucity of macroherbivores on the rocks, it appears that most of the primary productivity is exported, and most of the energy utilized by the suspension feeding assemblage is imported. Imported material is undoubtedly the dominant category.

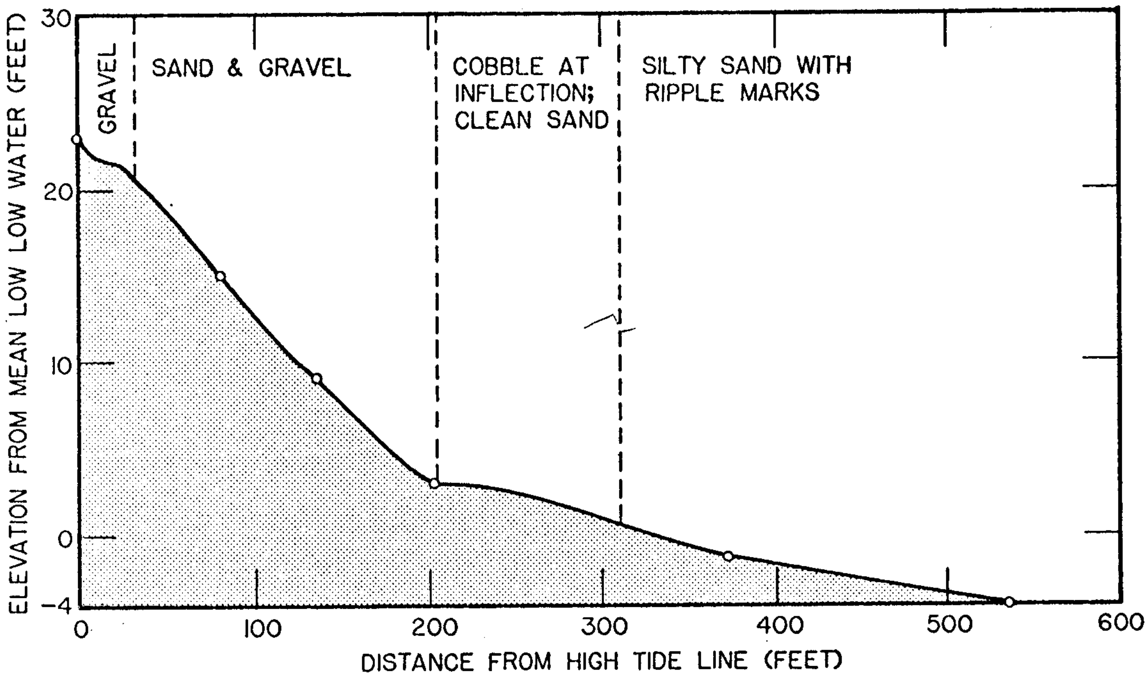
Casual observations were also made of nearshore bird life sighted at Whiskey Gulch. The most abundant nearshore species was the harlequin duck (Histrionicus histrionicus) with estimated densities of about 20 to 30 per mile. Oldsquaw (Clangula hyemalis) were also abundant with densities of perhaps 10 to 20 per mile of beach. Surf and white winged scoters (Melanitta perspicillata and M. deglandi) were seen flying offshore. A flock of about 10 dowitchers (Limnodromus sp.) was observed in the low cobble zone probably feeding on amphipods. Greater yellowlegs (Totanus melanoleucus) were seen in one of the back dune pools. Several gulls (Larus spp.) were also observed.

5.1.5 Deep Creek

Date: 5/17/76 Tide -3.4 feet at 1052
Location: Deep Creek Beach, south of the access road

The beach at Deep Creek (Figure 1) is rather similar to other beaches along the east side of Lower Cook Inlet in having a moderately steep upper beach of coarse sand and fine gravel with no macroorganisms evident. Drift material was sparse at the high tide line. At the base of this gravelly section, at about MLLW, the beach slope decreases sharply and substrate changes to become predominantly sandy with some pea-sized gravel and coal. No organisms were found in this clean, loosely compacted sandy area. At about -2 ft, the beach becomes flatter and the sand much siltier and more firmly compacted (Figure 7). In this area, especially 100 meters south of the beach entrance there was a rich, typical infauna. Dominant numerically in core samples were the haustoriids; several typical polychaetes were also present. Infaunal abundance tended to be greatest under surface runoff channels.

On the sand surface, an occasional hermit crab, P. kennerlyi was found, along with numerous sand lances and stranded epitokous (sexually mature, free swimming) nereid worms. Razor clams were also present although their peak abundance was probably below the lowest level exposed on the day of our visit. The amphipods Anisogammarus spp. were abundant in the seepage running over the beach surface.



BEACH PROFILE FROM DEEP CREEK
JULY 1976

DAMES & MOORE

FIGURE 7

The fauna on one large low boulder just above MLLW was somewhat impoverished consisting only of barnacles (*B. glandula* and *B. crenatus*), a few mussels and an encrusting red alga. A large percentage of the rock was covered by dead barnacle shells, probably due to winter icing conditions. The usual predatory gastropod, *Nucella emarginata*, was absent.

A larger boulder, well up the beach, had a more typical fauna including barnacles, mussels, limpets and periwinkles (Appendix A-6). Seaweeds were generally absent on the rocks.

This area supports a moderately impoverished suspension feeding assemblage that is totally dependent upon imported organic material. It appears that predators are largely restricted to transient species, such as shorebirds, fish and crabs, that move into the area with the tides.

In the pools among the sand dunes flanking the mouth of Deep Creek, six pairs of Canada geese (*Branta canadensis*) and several pintails (*Anas acuta*) were sighted.

5.1.6 Clam Gulch

Date: 5/14/76 Tide: -5.8 feet at 0833

Location: From opposite Clam Gulch beach access road to 1 mile south of road, below the cannery

Normal high tides at Clam Gulch (Figure 1) reach the base of the steep bluffs bordering the beach except in a very few small areas. As at Whiskey Gulch the uppermost intertidal area is a narrow band of sand below which is a broad band of loose small gravel and coarse sand. The slope of this band at Clam Gulch was less steep than at Whiskey Gulch but no macro-organisms were found in or on it even though it extended to MSL or below

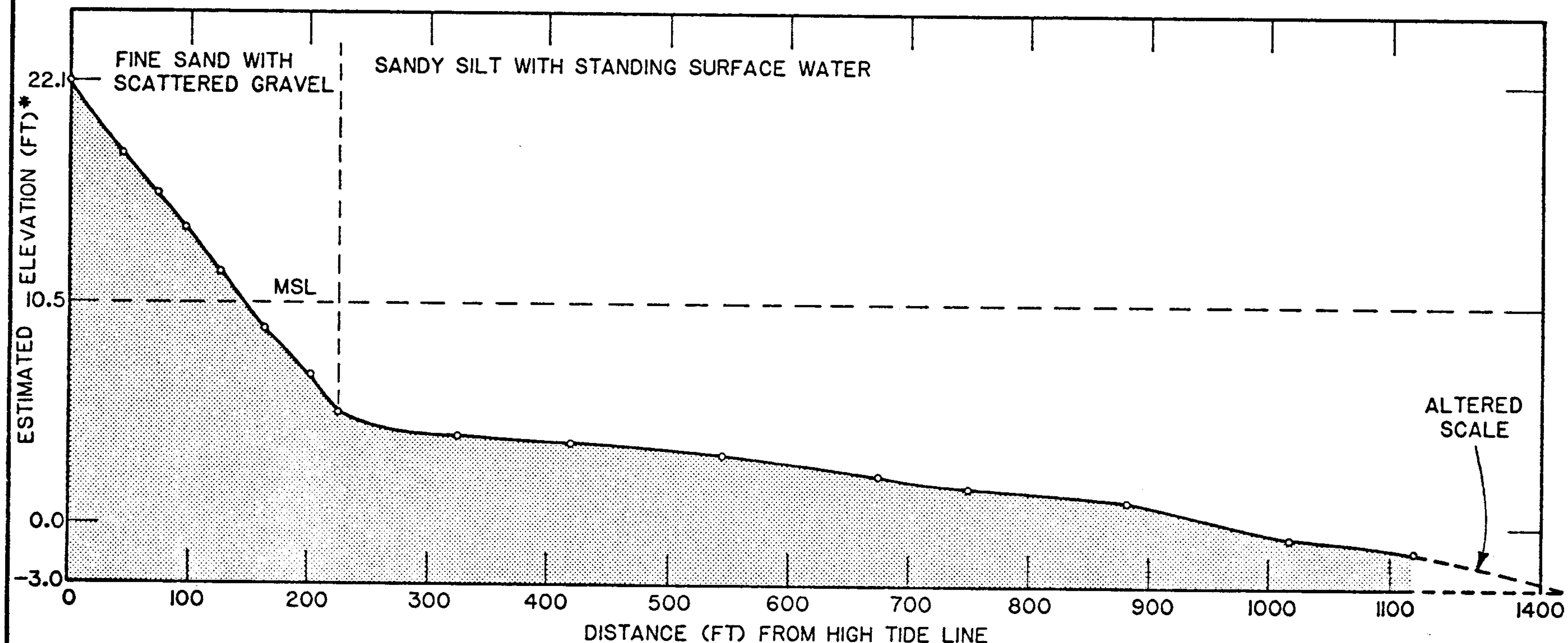
(Figures 8 and 9). Drift material was absent at the high tide line, but alder leaves were common on the low beach.

At the bottom of this gravel band the beach flattens rapidly onto broad silty sand flats where infauna becomes increasingly diverse and abundant with decreasing tide level. On the upper part of this beach (about -2 ft) the small infauna resembles that from Whiskey Gulch; haustoriid amphipods and a few small polychaetes dominate. At about -4 ft these organisms are somewhat more abundant and additional polychaete species are present.

Below about -4 ft, razor clam (Siliqua patula) densities increase sharply, supporting a tremendous recreational fishery during the few tide series low enough to permit digging. A weekday crowd (Friday) of some 1,000-1,500 diggers was present on May 14 and digger success was generally high. Densities appear to increase with increasing distance from the access road. About 1 mile south of the access, densities based on "shows" or siphon holes only were estimated to be near 1 per sq. m. overly relatively large areas. In many instances several shows (up to 5) were evident in a space of about 0.25 sq. m. Clams observed ranged in age from 2 to 8 or 9 years with the age structure shifted towards older individuals. Aging of razor clams was not sufficiently reliable to permit aging to all specimens taken but the length frequency data presented in Table 3 (Appendix A-7a) support that conclusion.

In addition to razor clams, some "rednecks" and a few cockles (Clinocardium nuttalli) were observed.

A number of other macroinvertebrates were seen in low densities in and on the broad silty sand beach from -4 to -5.5 ft. Several tanner crab (Chionecetes bairdi) were stranded and partially buried in the sand near the water's edge. Small shrimp (Crangon spp.) were also found partially buried in the moist sandy areas. The fleshy cylindrical bryozoan (Alcyonidium

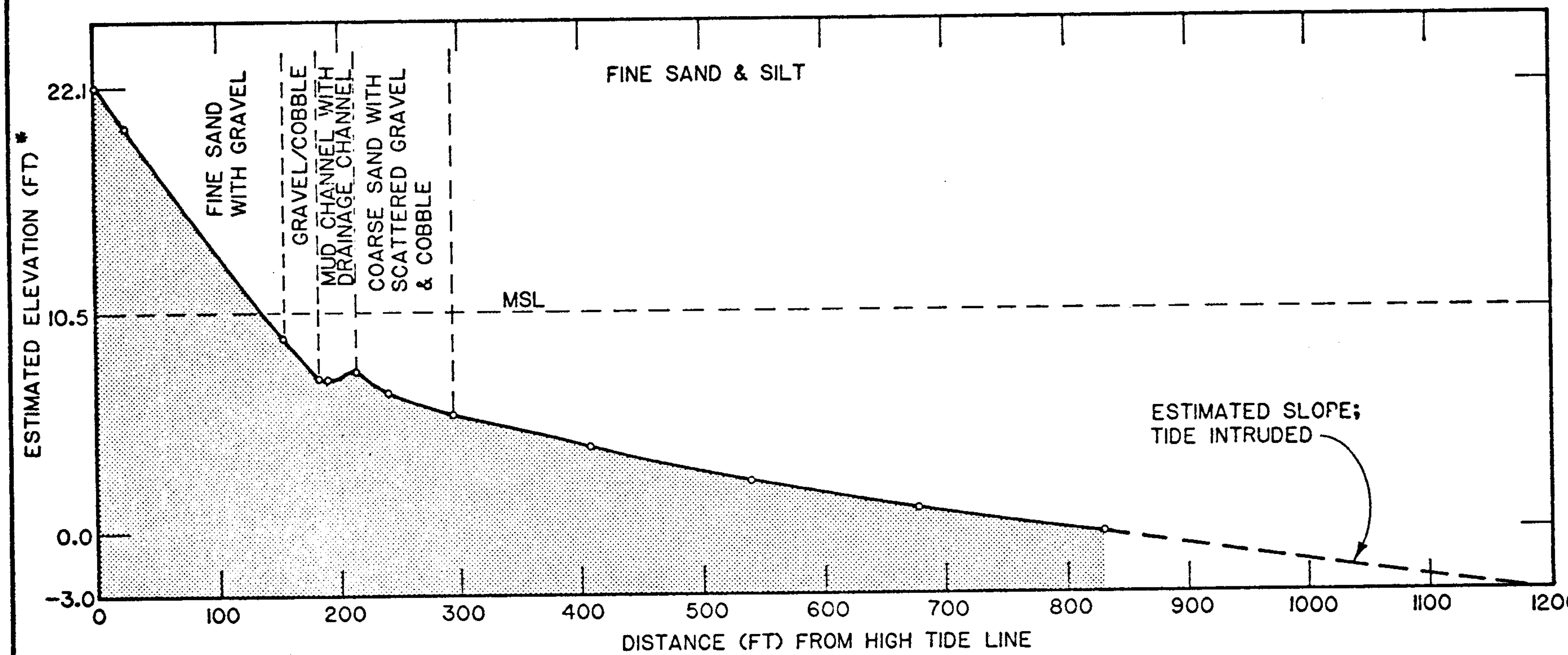


* BASED ON PREDICTED TIDE RANGES & INTERPOLATED CORRECTIONS

BEACH PROFILE FROM CLAM GULCH, NEAR THE ACCESS ROADHEAD
JULY 1976

FIGURE 8

DAMES & MOORE



* BASED ON PREDICTED TIDE RANGES & INTERPOLATED CORRECTIONS

FIGURE 9

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BEACH PROFILE FROM CLAM GULCH, NEAR CANNERY

JULY 1976

Table 3. Size distribution for the razor clams <u>Siliqua patula</u> from Clam Gulch on 5/14/76

Shell length (mm)	Frequency	Percent
90-94	1	1.9
95-99	0	0
100-104	0	0
105-109	1	1.9
110-114	4	7.5
115-119	3	5.7
120-124	8	15.1
125-129	18	34.0
130-134	10	18.9
135-139	7	13.2
140-144	0	0
145-149	1	1.9

n	53
$\bar{x}$	125.9
s	8.8

enteromorpha), attached to partially buried pebbles, was common, and a very large red and green anemone (Tealia sp.) was found attached to a buried cobble at the lowest tidal level exposed (about -5.5 ft). The burrowing anemone (Anthopleura artemisia) was common over large areas of the lower beach.

Infauna on this lowest beach was typical to that described for other low sand habitats. Large "blood" worms (Notomastus ?lineatus) and "sand" or "clam" worms (Nephtys nr caeca) were common along with several smaller forms.

Boulders in the Clam Gulch area were generally small and supported a very simple system that included only barnacles, mussels and a few of the predatory snails Nucella emarginata (Appendix A-7). Seaweeds were absent.

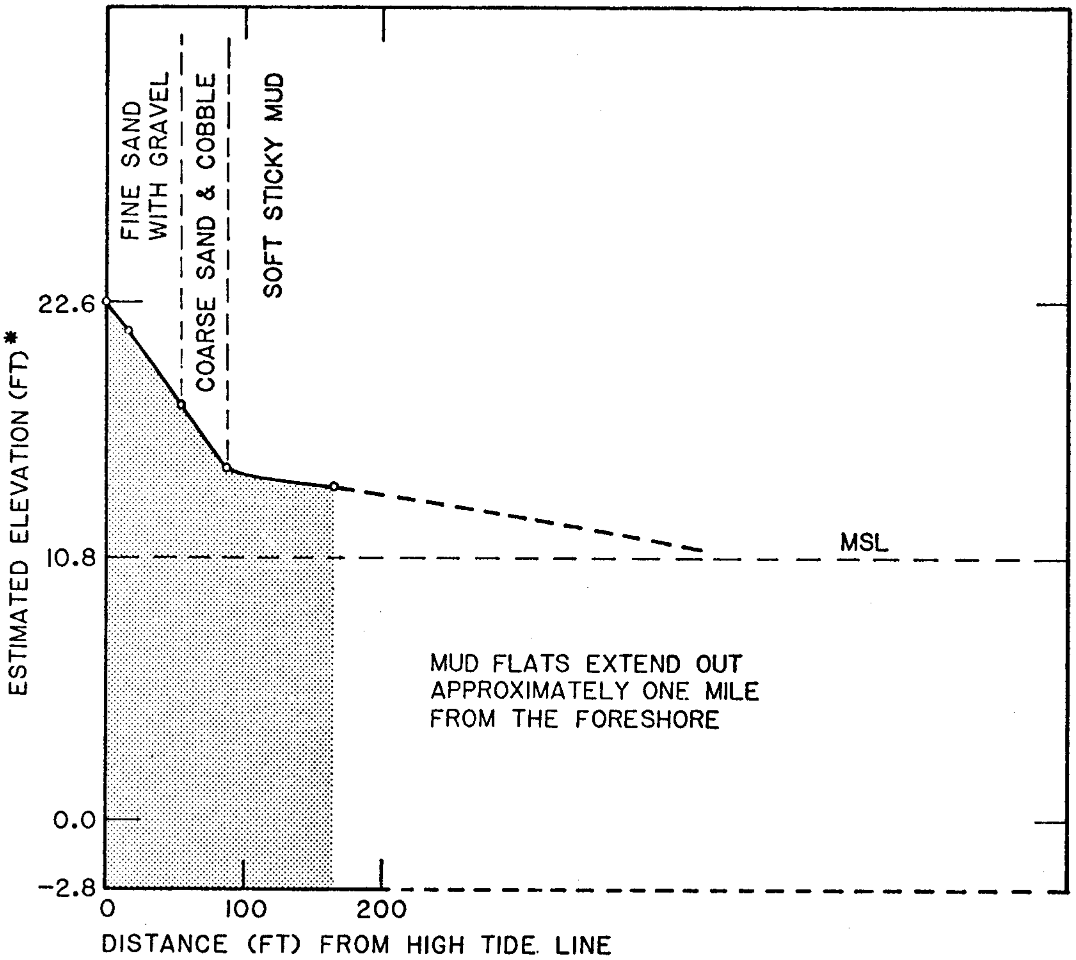
This area supports a moderately impoverished assemblage of suspension and deposit feeders that is totally dependent upon imported organic material. Predators appear largely restricted to transient species such as shorebirds, fish and crabs, that move about the area on a tidal cycle.

Perhaps because of the large numbers of people and vehicles on the beach, no birds other than gulls were observed nearshore.

5.1.7 Kasilof Beach

Date: 5/17/76 Tide: -3.4 feet at 1052
Location: About 0.25 miles north of mouth of Kasilof River

Sand dunes flank the mouth of the Kasilof River and their steeply sloping seaward face comprises the upper beach in this area (Figures 1 and 10). No organisms were evident in this sandy beach, although shells of the clam Macoma balthica were abundant. No drift material was observed. At the foot of this sandy beach (above MSL), the slope decreases abruptly and the substrate changes to a very sticky mud with much clay.



* BASED ON PREDICTED TIDE RANGES
& INTERPOLATED CORRECTIONS

BEACH PROFILE FROM KASILOF RIVER MOUTH
JULY 1976

DAMES & MOORE

FIGURE 10

This broad mud flat is of considerable extent reaching perhaps a mile from the high water mark even on the moderately low tide of May 17. Because of the unusually difficult walking conditions, observations of the mud flat fauna were confined to within about 100 meters of the sandy beach.

Only two macroorganisms were found. The small tellinid, M. balthica was abundant in both its pink and white forms and the lugworm A. pacifica was also moderately abundant. A diatom (?) film present on the mud surface was the only indication of algae (Appendix A-8).

The faunal assemblage in this area is stringently impoverished. It has the lowest diversity of all areas examined. Both species observed are deposit feeders. The area is totally dependent upon imported organic materials, with the possible exception of utilization of diatoms by Macoma.

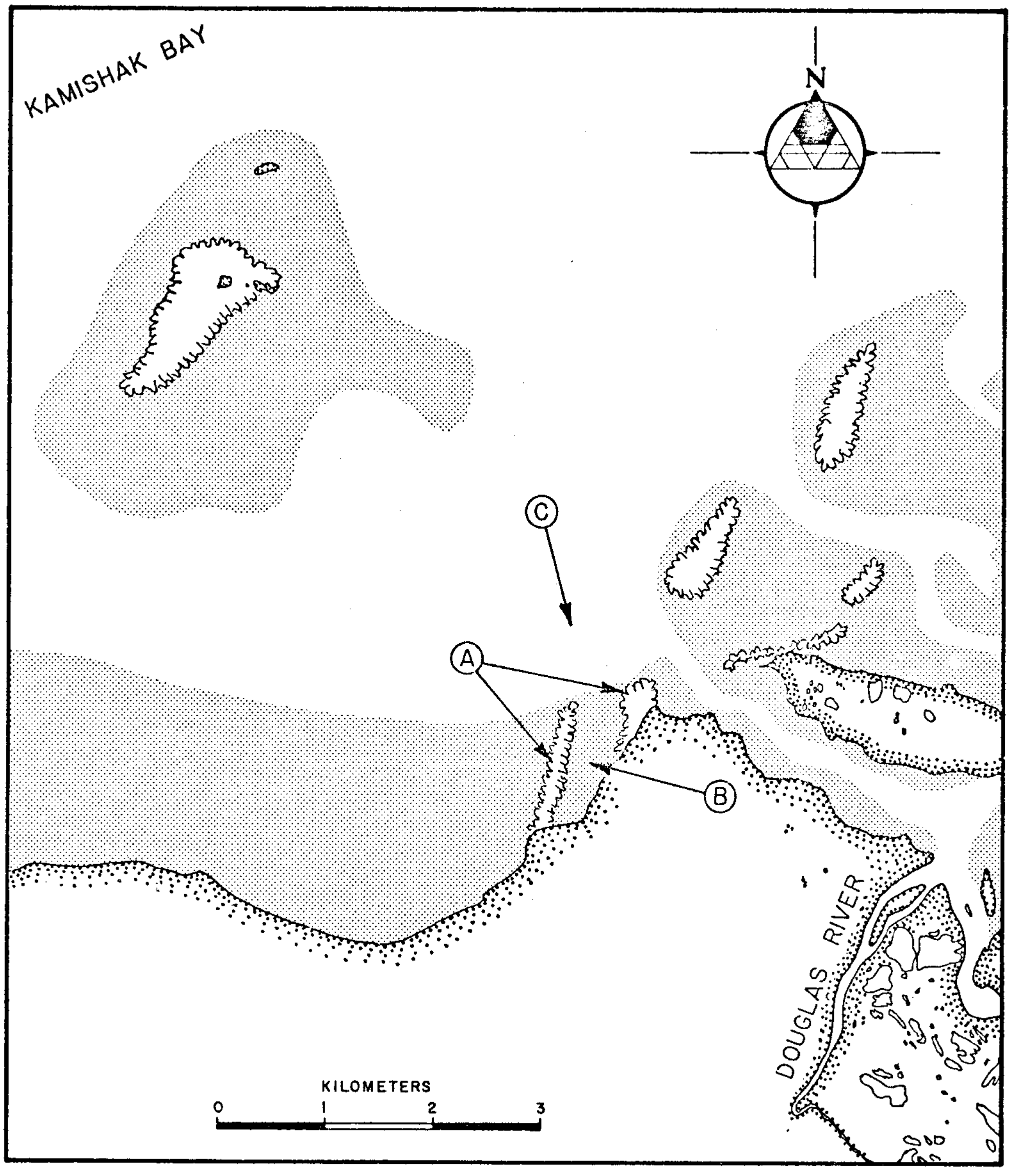
5.2 West Shore Study Areas

Study sites on the west side of lower Cook Inlet were occupied from near the mouth of the Douglas River, on the southern shore of Kamishak Bay, to Polly Creek, north of Tuxedni Bay. Habitat diversity on this side of the inlet is great. There is a wide variety of combinations of substrate types, turbidity and salinity conditions and wave exposure levels. Consequently, the area is biologically more complex and interesting than the areas examined on the upper Kenai Peninsula. Where observed, algal drift material at the high tide line was only light to moderate.

5.2.1 Douglas River

Date: 6/15/76 Tide: -3.3 feet at 1031

Location: About 2.5 miles west of the mouth of Douglas River



KEY:

(A) SANDSTONE BENCH
(B) MUD FLAT
(C) BROWN SAND BAR
TIDAL FLATS

DOUGLAS RIVER SITE

DAMES & MOORE

FIGURE 11

5.2.1.1 Rock

A relatively flat sandstone bench extends several hundred meters off shore over a large part of the area. This bench includes several levels in the vicinity of MSL. The top and sides are polished smooth by ice and were virtually devoid of organisms. Cracks and crevices contained most of the species typical of higher intertidal rock (barnacles and littorines) but many of the usual minor species were not found. Only a few mussels were present but the individuals seen were mainly large. A recent heavy set of barnacles had occurred.

On lower levels of the bench the biota contained several typical animals (barnacles, littorines, and Nucella), some algae (Fucus and Rhodomela) and some eelgrass in silty sand pockets and drainage channels (Appendix B-1). The bryozoan Eucratea loricata was common around boulders at this level. The low diversity of organisms was probably due to the effects of ice scour.

The under rock fauna on the lowest benches was fairly rich and included several typical Crustacea (Anisogammarus spp., Ampithon s. A., Gnorimosphaeroma oregonensis, Pagurus hersutiusculus, and Idothea ochotensis) and mollusks (Nucella, Mopalia lignosa and breeding littorines) as well as a few anemones, the sea cucumber, Chiridota sp., and the starfish Leptasterias hexactis.

5.2.1.2 Mud

Silty pockets and channels on the sandstone bench, as well as a protected much beach adjacent to the bench, contained very dense soft shelled clams (Mya spp.) and the small Macoma balthica. Mya reached densities of over 300 per sq. m. in nonrandom sampling with an average of 39.4 per sq. m. in 34 random casts (Table 4). M. balthica densities were estimated to reach 400 per sq. m. The lugworm, Abarenicola pacifica, also had densities of several

Table 4. Frequency of *Mya ?arenaria* in 1/4 sq. m. quadrats, Douglas River, 6/15/76

Number of *Mya* per quadrat	Frequency on lower mud flat	Frequency on upper mud flat
0	4	14
1	1	1
2	1	1
3	1	0
4	2	2
5	2	0
6	0	2
7	1	0
8	2	0
9	4	0
10	3	0
11	1	0
12	2	0
13	1	0
14	2	0
15	0	0
16	0	1
17	2	0
18	1	0
19	0	0
20	3	0
34	1	0
n	34	21
$\overline{x} \pm s$ (individuals/quadrat)	9.85 ± 7.43	1.86 ± 3.82
Density	$\sim$ 39.4/sq. m.	7.4/sq. m.

hundred per square meter in places (Appendix B-1).
The spoonworm Echiurus echiurus alaskanus was common. Nephtys nr caeca and other typical mud dwelling forms were present in lesser numbers. Considerable evidence was found of seagull (Larus spp.) predation on Balanus, M. balthica and Pagurus sp.

5.2.1.3 Sand

Seaward of the sandstone benches, from about MLLW down, the beach flattens into broad gently rolling sand extending out perhaps a half mile. Distributaries of the Douglas River meander across this flat at low tide. The fauna of this beach was generally typical of other low sandy areas At least seven species of bivalves were found here including two species of razor clams. Siliqua patula, the more common type was less abundant than at the Chinitna Clam Beach or Polly Creek but reached densities approaching 1 per aq. m. in places. Siliqua alta, a less common form found also at Seafair Beach near Homer, was found in very low densities only in siltier sands near the bench. Several very large Mya, possibly M. elegans, were also found in silty sand near the rock bench. The isopod Saduria entomon was common near the rock bench burrowing through the thin silty layer that covered the sand (Appendix B-1).

The trophic dynamics of this area were moderately complex. Basically, the area supports a broad variety of suspension feeders, but deposit feeders are common. Primary production on the rock bench is fairly low, and probably nearly totally exported. The preponderouse of organic material utilized is probably imported. The major predators observed were seagulls, surf scoters and the snail Nucella.

5.2.2 Amakdedori Beach

Date: 7/13/76 Tide: -3.7 feet at 0930
Location: About 1 mile south of Amakdedori Creek

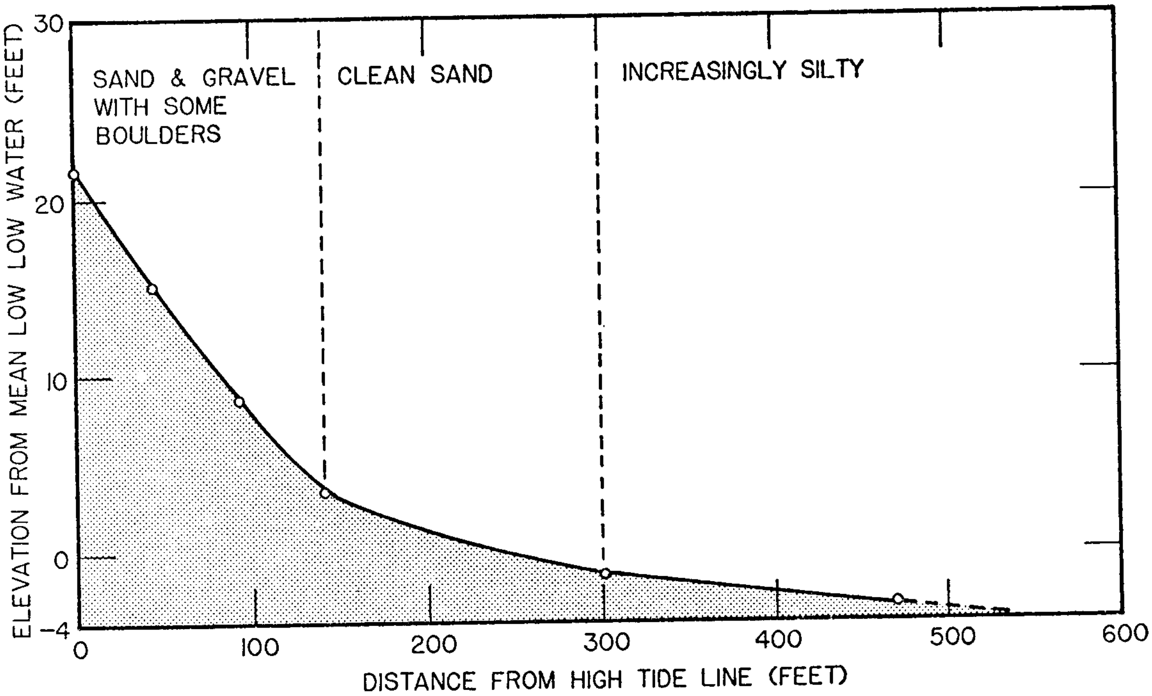
The upper beach at Amakdedori (Figure 12) is of moderately steep coarse sand and gravel. Below about +2 feet the slope decreases and the substrate changes to sand; silt concentration is inversely proportional to tide level (Figure 12). The beach is cut at intervals of several hundred meters by rock outcroppings.

5.2.2.1 Sand

No organisms were found in the steep mixed coarse upper beach or in the sand portion much above MLLW. Beginning at MLLW the lugworm, *Abarenicola pacifica* was common (Appendix B-2). Below MLLW several typical low sand polychaetes were present (*Nephtys* and spionids). A new set of razor clams (*Siliqua patula*) had occurred, densities of 114/sq. m. were estimated from core data at -3 ft. These clams averaged 4.17 mm. in length. No adult razor clams were found. Haustoriids were not found at this beach but *Anisogammarus ?pugettensis* was very abundant under each bit of drift algae on the beach. The absence of macrofauna, particularly clams, is peculiar.

5.2.2.2 Rock

The rock bench adjacent to the beach lacks the extensive flattened upper surfaces found at Douglas River but had a somewhat similar biota. Algae covered about 25% of the rock below MLLW. Dominant species were red algae, including *Callophyllis* sp., *Ahnfeltia plicata*, *Polysiphonia hendryi* and *Rhodomela larix*. A dense barnacle set covered nearly 100 percent of the rock in many areas, and even encroached on the encrusting sponge *Halichondria*, another abundant organism. However, the lack of older barnacles and other sessile organisms except in protected crevices suggests that ice abrasion plays a major role in limiting epifauna here. Some typical algae and fauna were present in protected areas and the under rock fauna was reasonably rich. Particularly notable were the hermit crab, *Pagurus beringanus*, the starfish *Leptasterias hexactis*, the fleshy



BEACH PROFILE FROM AMAKDEDORI BEACH
JULY 1976

DAMES & MOORE

6797-004 NYM 7/28/76

FIGURE 12

encrusting bryozoan Alcyonidium polyoum, and the crescent gunnel Pholis laeta (Appendix B-2).

The trophic dynamics at this site were moderately simple. Primary productivity is probably low, especially if considered on an annual basis. No herbivores were observed. Scavengers were common on the rock habitat and several predator species were noted. However, the total system was dominated by suspension feeders, such as barnacles or sponges, and deposit feeders, such as the lugworm. A great preponderance of the organic material required is probably imported.

5.2.3 Bruin Bay

Date: 6/14/76 Tide: -4.5 feet at 0949

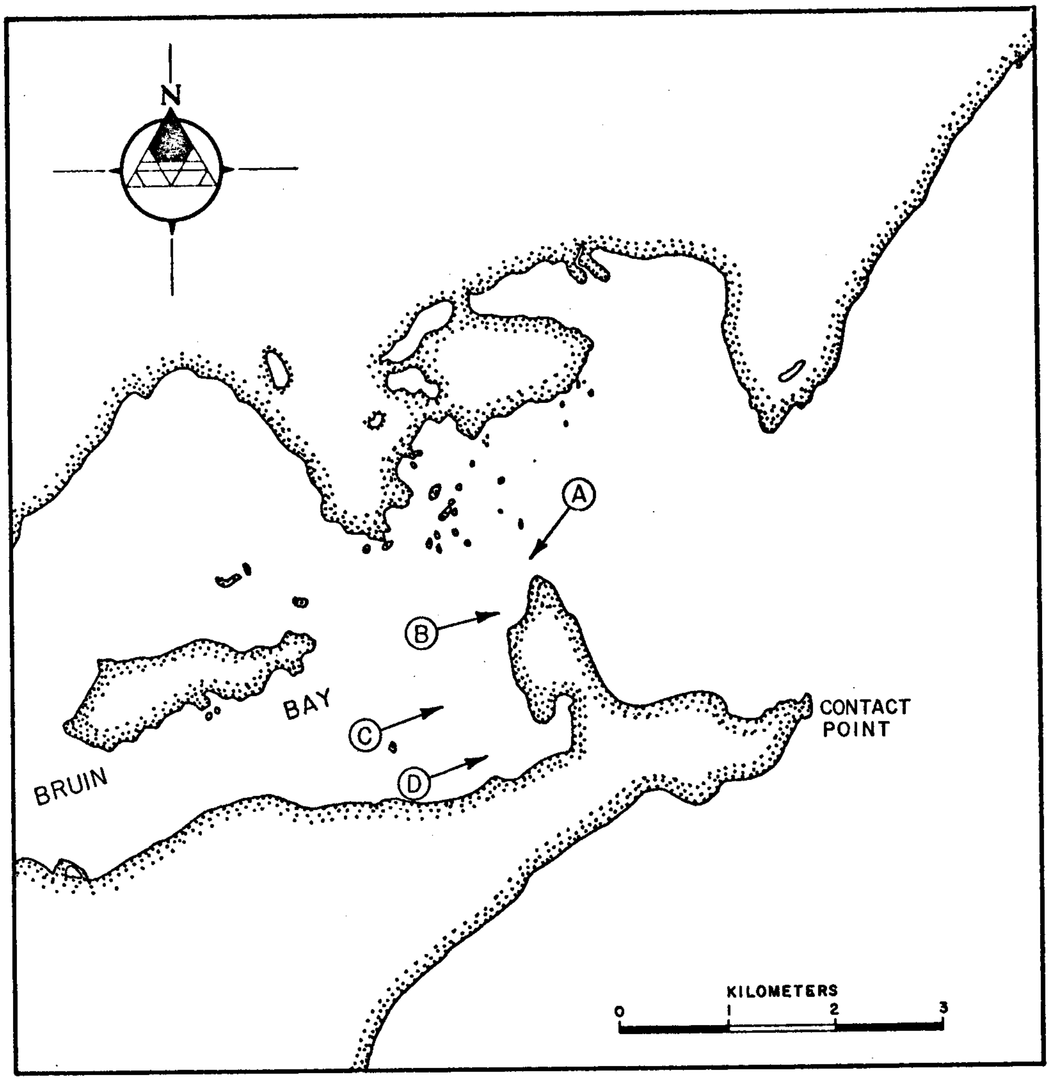
Location: Rock point 2 miles WNW of Contact Point and "Brownie Cove", inside Bruin Bay, 1.5 mi W. of Contact Point

5.2.3.1 Rock

The rocky point examined is part of the entrance channel into Bruin Bay (Figures 1 and 13) and therefore subjected to strong, reversing currents twice each day. Consequently, it is swept clean and relatively silt-free.

The upper rocks are the continuation of a low headland and are mainly bedrock. They supported a rather typical fauna, except for the paucity or absence of limpets and motile crustaceans.

In the vicinity of MLLW, algae were conspicuous, particularly the green alga Enteromorpha intestinalis. Somewhat lower, additional seaweeds became common, especially rockweed (Fucus distichus), Laminaria saccharina, and Rhodymenia palmata. The sponge Halichondria was also



KEY:

(A) ROCKY POINT
(B) SAND/GRAVEL/BOULDER FIELD
(C) MUD FLAT/GRAVEL BED
(D) EELGRASS BED

BRUIN BAY SITE

DAMES & MOORE

FIGURE 13

quite common on the sides of rocks and on the bottom of tide pools. However, the most conspicuous feature on the exposed rocks around Bruin Bay was the coverage by barnacle spat, which frequently completely obscured the rock surface from view. In fact, because of the concentration of crushed barnacles under foot, footing was treacherous on the lower intertidal rocks. Under and around boulders, common species were the snails *Littorina sitkana* and *Nucella emarginata*, a predator on barnacles, the amphipod *Anisogammarus ?confervicolus*, a hermit crab *Pagurus beringanus* and a starfish *Leptasterias ?hexactis*, a predator on barnacles and *Littorina* (Appendix B-3).

Similar habitat and the associated biota extended about 0.5 miles into Bruin Bay on the southwest, but this was not examined in detail. Similar barnacle cover on the rocks also extended at least 0.5 miles toward Contact Point on the east, and, because of observations at Douglas River and Amakedori, it appears probable that the condition prevailed for much of southern Kamishak Bay.

5.2.3.2 Sand and Gravel

At "Brownie Cove", inside Bruin Bay, the area is mainly dominated by a silty sand or mixed fine substrate. These substrates supported strongly differing biotic assemblages, particularly with respect to flora (Appendix B-4).

The silty sand habitat was dominated by an extensive young population of eelgrass (*Zostera marina*) on the south side of Bruin Bay. Density of turions (leaf bundles) in the area averaged 497.6 per sq. m. (Table 5; Appendix B-4a). Based on the relationship determined for turion density and relative cover (Figure 14), vegetative cover was at least 30% in June. Average length of turions was short (Table 6; Appendix B-4b) relative to locations examined on the southern Kenai Peninsula and by

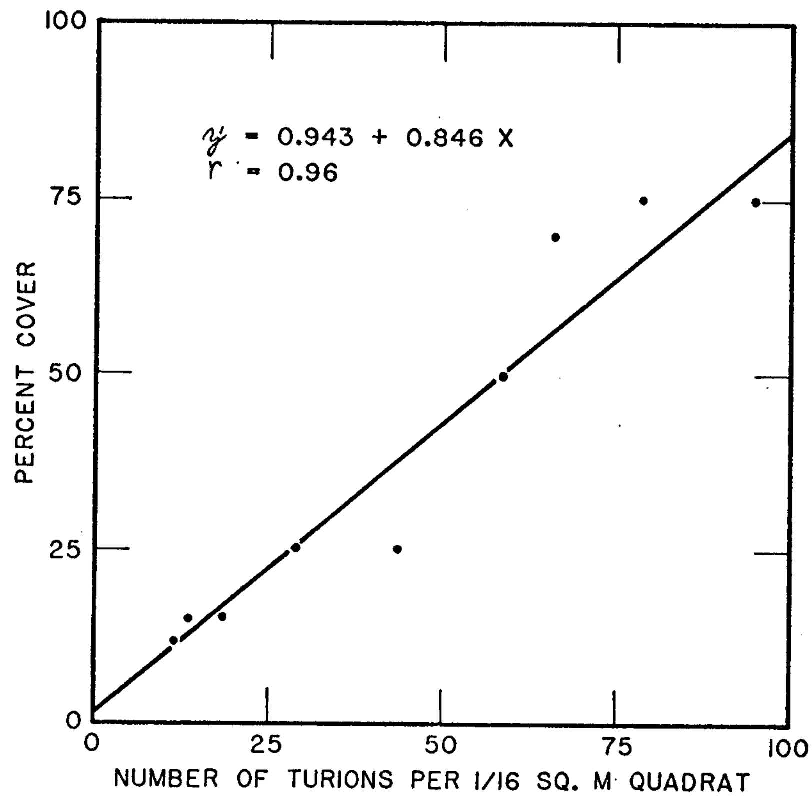
Table 5. Number of turions (leaf bundles of *Zostera marina* in 1/16 sq. m. quadrats in eelgrass bed at Bruin Bay, 6/14/76

Number of turions per quadrat	Number of quadrats
0-9	6
10-19	6
20-29	1
30-39	1
40-49	1
50-59	4
60-69	2
70-79	1
80-89	0
90-99	1

$\bar{x} \pm s$ + 31.1 $\pm$ 28.7 turions/quadrat *

No./sq. m. : 497.6 turions

*based on computations from unclassed data in Appendix B-4a.



RELATIONSHIP BETWEEN TURION DENSITY
& PERCENT COVER IN EELGRASS BED,
FROM BRUIN BAY
JUNE 14, 1976

DAMES & MOORE

FIGURE 14

Table 6. Size distribution of *Zostera marina* from Bruin Bay, 6/14/76

Length (cm)	Frequency	Percent
17-18	7	10.2
19-20	4	5.8
21-22	21	30.4
23-24	10	14.5
25-26	14	20.3
27-28	7	10.2
29-30	3	4.3
31-32	2	2.9
33-34	0	0.0
35-36	1	1.4

n 69

$\bar{x}$ 23.6

s 3.6

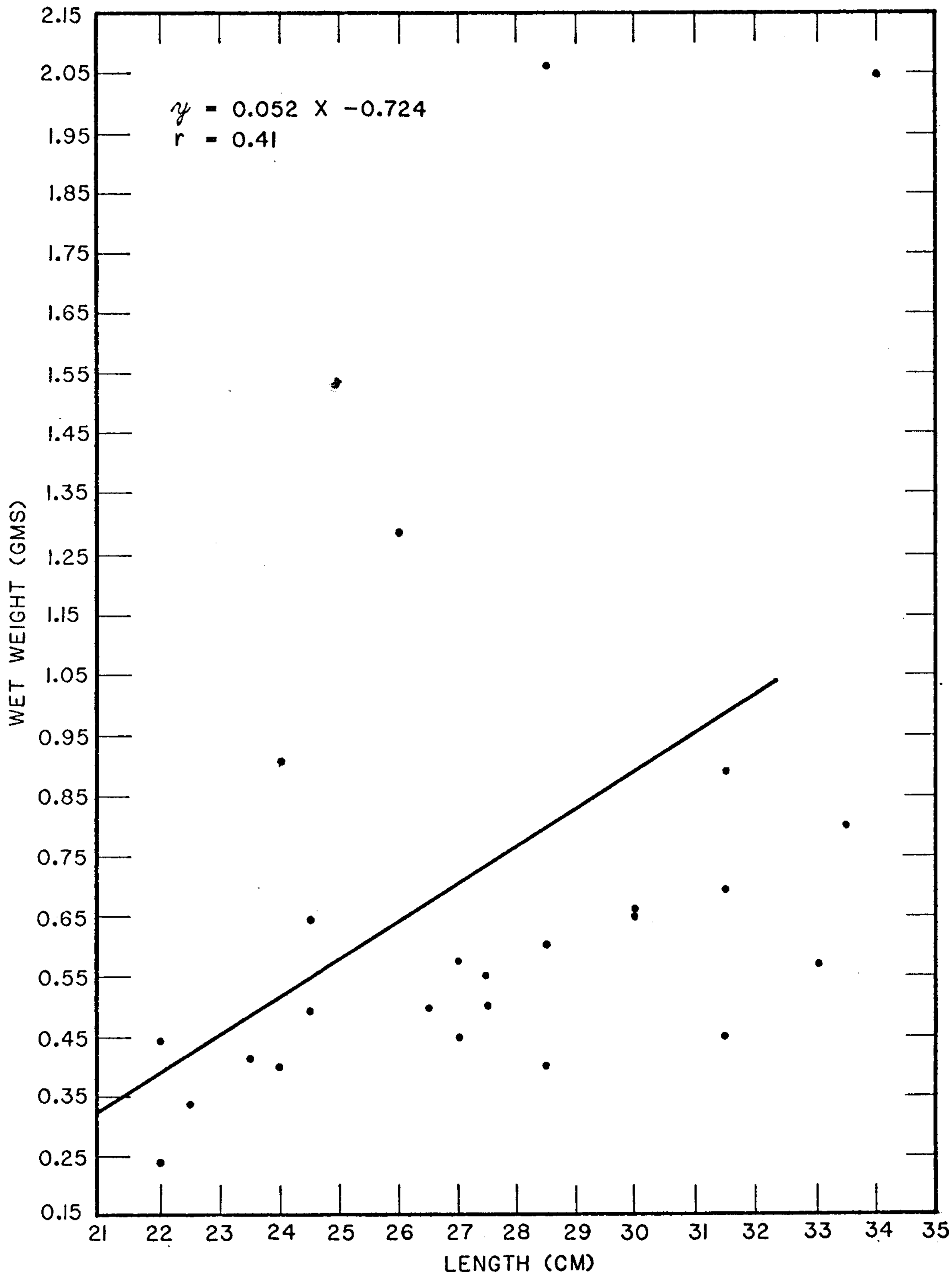
Range = 17-36

McRoy (1972). Length-weight relationships were examined for the turions (Figure 15) and were highly variable (Appendix B-4c). It is suspected that the main reason for the shortness of the leaves is that the turions had been torn away from the rhizomes by ice during the winter and that the bed was in the early stages of regeneration. In support of this hypothesis is the fact that, during the aerial reconnaissance, which took place in late May, eelgrass was noted as absent in Bruin Bay, but was plainly visible from the air in mid-June and quite conspicuous in mid-July.

Several other species were common in the eelgrass bed. These included some algae such as ?Monostroma, Polysiphonia, and Laminaria saccharina. A small burrowing anemone appeared to be restricted to the beds, as well as the amphiopod Caprella drepanochir. The clams Macoma balthica and Mya spp. were common inhabitants.

On the outer edges of the intertidal flats and in the channels, in areas with greater water flow, the substrate was composed of gravelly sand with silt and scattered boulders. The proportions of silt, sand and gravel varied considerably, but the flora and fauna appeared mainly to respond to tidal level (immersion). Greatest concentrations of algae were on the scattered boulders, but L. saccharina, was frequently attached to cobbles. The characteristic algal species on the boulders were Spongomorpha, Fucus, Halosaccion, Odonthalia kamschatica, and Rhodymenia palmata. Most of these species were only abundant in the lower part of the intertidal, however.

Dominant macrofaunal forms in the higher mixed fines habitat were the polychaete Nephtys nr. caeca and Mya ? arenaria; approximate densities are indicated in Table 7. Also common were the spoonworm Echiurus echiurus alaskanus, M. trancata, and the telliuid clams Macoma balthica and M. obliqua (Appendix B-4).



RELATIONSHIP BETWEEN TURION LENGTH & WET WEIGHT FOR ZOSTERA MARINA FROM BRUIN BAY, JUNE 14, 1976

DAMES & MOORE

FIGURE 15

Table 7. Density of two important infaunal organisms on mudflats in Brownie Cove, Bruin Bay, 6/14/76

No. per 1/4 sq. m. quadrat	*Nephtys* nr. *caeca*	*Mya* ? *arenaria*
0	11	12
1	6	3
2	4	1
3	1	1
4	0	0
5	0	2
6	1	0
7	0	1
8	0	0
9	0	0
10	0	0
11	0	1
12	0	2
13	1	0
33	0	1
$\bar{x} \pm s$	1.5 ± 2.8	3.9 ± 7.4
No. per sq. m.	6.0	15.5

The macrofauna on the boulders was generally typical of the mid to lower intertidal zones on rock, but diversity and densities were generally low.

The trophic dynamics of the Bruin Bay area are moderately complex. Primary productivity is probably fairly high as consequence of the eelgrass and the fairly common laminarians. Only microherbivores such as limpets were observed but migrating geese and ducks may consume a substantial quantity of eelgrass in the fall. However, it appears that the majority of the primary productivity is exported. Basically, the faunal assemblages are dominated by suspension feeders, but deposit feeders and scavengers are common. Other than the snail Nucella, abundant on rocks below MLLW, predators were uncommon. The main portion of organic material utilized in this system is probably imported.

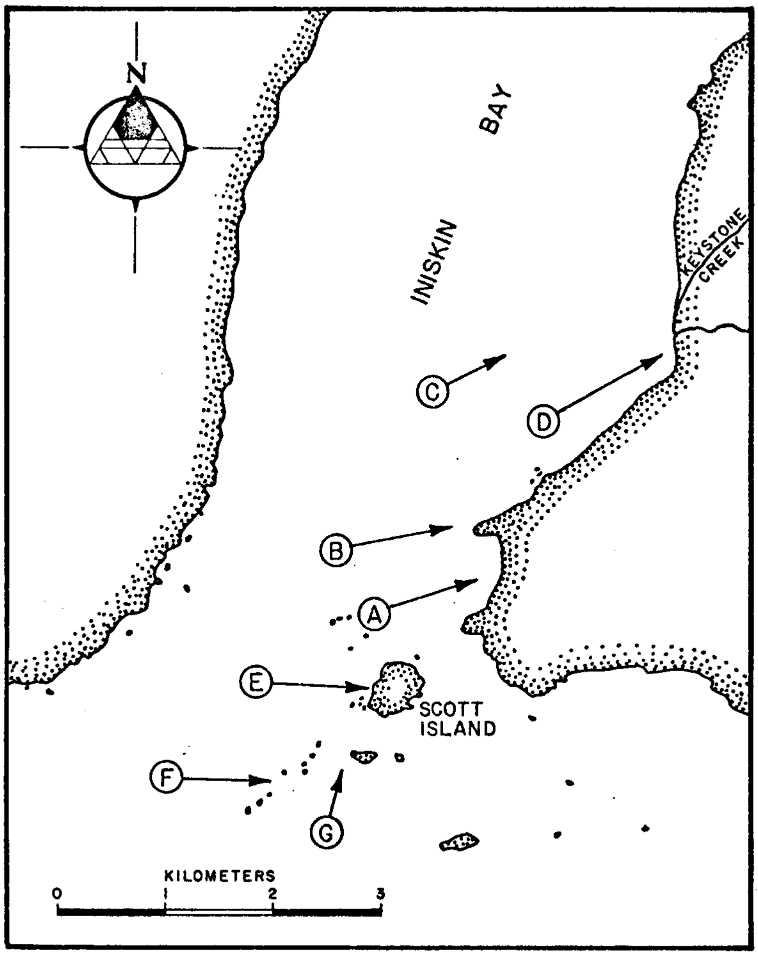
5.2.4 Iniskin Bay

Date: 6/12 and 6/13/76 Tide: -5.3 feet at 0820
and -5.2 feet at 0904

Location: "Blackie Cove", about 1 mile ENE of Mushroom Islet, and Fossil Beach, off the mouth of Keystone Creek

5.2.4.1 Sand, gravel and mud

The upper intertidal zone at "Blackie Cove" (Figure 1 and 16) is a moderately sloping clean sand and gravel beach. The high tide drift line had a moderate mount of algal debris that was inhabited by a large number of the beachhopper Orchestia sp. This species was particularly active at night. Other than that, the slope was devoid of animals down to MLLW, where the slope became gentle and the substrate changed to fine mud with some cobbles. On the mud, very near MLLW, the spoonworm Echiurus



KEY:

- (A) MUD FLAT – BLACKIE COVE
- (B) ROCKY POINT – BLACKIE COVE
- (C) LOW ROCK BENCH – FOSSIL BEACH
- (D) MUD FLAT/MID INTERTIDAL ROCK BENCH – FOSSIL BEACH
- (E) SOUTH OF INISKIN ROCK
- (F) NORTHEAST OF INISKIN ROCK
- (G) WEST SIDE OF SCOTT ISLAND

INISKIN BAY SITE

DAMES & MOORE

FIGURE 16

echiurus alaskanus was abundant; its density was about 35 individuals per sq. m. Lower on this mud flat, spoonworm density declined considerably, but soft shell clams (Mya spp.) and clam worms (Nephtys nr. caeca) became common. Densities were about 0.7 and 1.8 individuals per sq. m., respectively, for Mya and Nephtys. Other clams uncommonly observed in the area were the pink clam Macoma balthica and a large gaper Panomya ?ampla. The sand lance Ammodytes hexapterus was commonly encountered burrowing in the mud.

Vegetation was fairly diverse for a mud flat. Scattered patches of eelgrass were common toward the middle of the mud flat. Additionally, Laminaria saccharina, Scytosiphon lomentaria amd Iridaea lineare were common (Appendix B-5).

On a mud flat about 2 miles north of Keystone Creek (Figure 16), conditions and biota were rather similar. Several differences were observed, however. Algal diversity was somewhat lower, soft shell clams were more dense, and the basket cockle Clinocardium nuttalli and Macoma balthica were common (Table 8). Notable was the discovery of the priapulan Priapulus caudata (Appendix B-6).

5.2.4.2 Rock

At the lower edge of this mud flat, adjacent to a rock bench, Laminaria groenlandica was common and many of the organisms were more representative of the rocky habitat.

Rocky substrate was examined at a point on the northern end of "Blackie Cove", and at Keystone Creek. Near MSL, the two areas differed considerably physically and biotically. At "Rocky Point", the rock is steep and clean. Off Keystone Creek, the bench is rather flat and a thin layer

Table 8. Density of three important infaunal organisms on mudflats off Keystone Creek, Iniskin Bay, 6/13/76

Number per 1/4 sq.m. quadrat	*Mya ?arenaria*	*Nephtys caeca*	*Clinocardium nuttalli*
0	4	15	22
1	3	4	3
2	4	3	0
3	2	2	0
4	2	1	0
5	3	0	0
6	4	0	0
7	1	0	0
8	1	0	0
12	1	0	0
$\bar{x} \pm s$	3.6 ± 3.0	0.8 ± 1.2	0.1 ± 0.3
No./sq. m.	14.6	3.2	0.5

of silt is deposited on the rocks and encrusting animals. Also the under rock habitat is siltier. The dominant plant in both locations was rockweed. The barnacle Balanus glandula was abundant and covered a considerable proportion of the rock. Ther periwinkle Littorina sitkana was common. In spite of its siltiness, the flat bench off Keystone Creek was more diverse and supported a greater abundance of organisms. In addition to the animals cited above, it supported appreciable populations of small blue mussels, limpets, the clams Mya ?arenaria and Macoma balthica in silt pockets, and the whelk Nucella emarginata. Under boulders, the gammarid Anisogammus ?confervicolus, the hermit crab Pagurus hirsutiusculus and the crescent gunnel Pholis laeta were common. Both Littorina and Nucella were laying eggs under the rocks.

The zone between MSL and MLLW was examined at "Rocky Point", where the substrate was a moderately sloping bedrock bench with scattered boulders. Dominant macrophytes in this zone were red and green algae. The red algae included mainly Rhodymenia palmata and Callophyllis sp.; Enteromorpha intestinalis, Spongomorpha sp. and ?Monostroma sp. were the most abundant greens. The brown algae Alaria sp. and Laminaria saccharina were present at this level, but were more common toward MLLW (Table 9).

In terms of biomass, cover and visual impact, the dominant organisms were the yellow encrusting sponges Halichondria panicea and Haliclona permollis, which were growing in large patches on the sides of rocks and on moist flat surfaces. Other animals that were common in exposed situations were Littorina sitkana, limpets, the blue mussel, and Balanus glandula. The small six-rayed starfish Leptasterias hexactis was abundant under rocks. Up to 100 were observed in some areas. Some were brooding eggs. The unimodal size distribution (Table 10) for this brooding species is difficult to interpret at this time. Also under boulders in this area, the horse crab Telmessus cheiragonus and the cresent gunnel were common. Circular colonies of an encrusting bryozoan were common growing on the bottom of rocks.

Rocky substrates below MLLW were examined both at "Rocky Point" and on an isolated rocky bench off Keystone Creek. The "Rocky Point" site was the cleaner of the two locations and supported a more diverse and luxuriant biota. However, many of the important species were the same. These included such algae as Spongomorpha, Laminaria saccharina and L. groenlandica, Iridaea lineare and Rhodymenia palmata (Table 9 and 11); the sponges Haliclona, Halichondria and Suberites; the large yellow anemone and Tealia crassicornis on the sides of rock; various barnacles, the crab Hapalogaster mertensii under rocks, the shrimp Heptacarpus stimpsoni, the isopod Idothea ochotensis on seaweeds, the decorator crab Oregonia under rocks, along with various species of Pagurus; the nestling clam Hiatella arctica, the predatory snails Neptunea lirata and Nucella emarginata; the bryozoans Alcyonidium polyoum and Terminoflustra membranaceo-truncata both under rocks; a sea cucumber Chiridota sp., which burrows in the mud under rocks, and the starfish Leptasterias hexactis, and the large predatory L. polaris acervata, on the sides of rocks and in channels; and the fishes Anoplarchus purpurescens and Pholis laeta, under rocks. The under rock assemblages were quite similar. The dominant patterns of Laminaria species (Table 9 and 11) are a notable difference between the two areas.

An important finding was the discovery of numerous juvenile king crab (Paralithodes kamtschatica) under large boulders at "Rocky Point"; up to six were observed under some rocks (Appendices B-6 and B-7).

Both locations were rich intertidal areas; in fact, either area was richer than any other rocky intertidal areas examined. The trophic dynamics of these areas were complex, but although microherbivores such as limpets and chitons were common, macroherbivores were uncommon or absent. Apparently the macrophytes contribute little directly to the biotic assem-

Table 9. Percent cover at lower and mid tide levels at rocky point, Blackie Cove, Iniskin Bay, 6/12/76

	1/4 sq.m. Quadrat	Laminaria groenlandica	encrusting alga	sand/ gravel or rock	Rhodymenia palmata	filamentous green algae	? Monostroma	Laminaria saccharina	Fucus distichus	Callophyllis	Alaria
Lower tide pools	1	60		40							
and rocks	2	80		20							
	3	20		80							
	4	50	10	45							
	5	60		40							
	6	80		20							
	7	70		30							
	$\bar{x} \pm s$	60.0 ± 20.8	1.4	39.3 ± 20.5							
Rocks around	1			40	20	15	5	2	0	0	
MLLW	2			30	30	25	0	0	20	11	
	3			0	50	50	5	0	0	0	
	4			0	60	5	15	0	0	0	
	5			30	0	0	2	30	0	0	50
	6			15	60	2	3	0	0	0	30
	7			5	40	0	0	0	0	0	60
	8			0	15	60	0	25	0	0	
	$\bar{x} \pm s$			15.0 ± 16.3	34.4 ± 21.9	19.6 ± 23.6	3.8 + 5.0	7.1 ± 12.7	2.5	1.4	17.5 ± 25.5

Table 10. Size frequency data for Leptasterias hexactis under rocks on Rocky Point, Iniskin Bay, 6/12/76

Maximum radius (mm)		Frequency
17		2
18		1
19		2
20		9
21		4
22		17
23		7
24		5
25		13
26		8
27		3
28		4
29		2
30		2
31		0
32		1
33		5
34		0
35		1
	Total	86

$\bar{x} \pm s = 24.2 \pm 3.9$ mm.

blages. Suspension feeders and scavengers were very abundant and comprised a broad variety of species. Predators, while far less abundant, also were a diverse group. Deposit feeders were locally abundant.

Generally it appears that the faunal assemblages in these areas depend very heavily on the tidal currents and the entrained suspended organic material. It is in this indirect manner that the algal assemblage ultimately contributes to the food supply of the fauna of these reefs. After being macerated by transport through many tidal cycles, drift algal material finally becomes small enough to be ingested by the suspension feeders.

5.2.4.3 Iniskin Bay

Date: 8/24/76; about 0800 Tide: about -1.7 at 0740
Location: Rocky Point, "Blackie" Cove

The intertidal area observed at this site was mainly a bedrock finger extending westward into the entrance channel of Iniskin Bay from the eastern shore. The rock surface is fairly smooth and free of loose material; boulders are generally fairly large. This site was visited previously (6/12/76); the purpose of returning was to re-examine the plant assemblage toward the end of the summer growing season.

The biota was strongly dominated by several species of algae (Appendix B-7a). Of particular importance were rockweed (*Fucus distichus*), the foliose red algae *Rhodymenia palmata* and *Callophyllis* sp., and the filamentous green alga *Spongomorpha* sp. (Table 12).

Most of the plant species common in the area were "pioneer" species. This is particularly true for *Spongomorpha*, *Callophyllis*,

Table 11. Percent cover below MLLW on rocky bench off Keystone Creek, Iniskin Bay, 6/13/76

1/4 sq. m. Quadrat	*Laminaria saccharina*	*Rhodymenia palmata*	*Porphyra* sp.	?*Monostroma* sp.	*Pterosiphonia* sp.	Rock, sand or mud
1	20	70				10
2			2			98
3	70	5				25
4	40	15				45
5	80	10				10
6	99					1
7			1			99
8	80	20				0
9	100					0
10	60			2		35
11		40		5	35	20
12	95	5				
$\bar{x}$	53.7	13.8	0.3	0.7	2.9	31.2
s	40.0	21.3				36.3

Porphyra, and Rhodymenia. It is notable that the major pioneer species are located in the mid-intertidal zone, where the effects of emersion, freezing and ice abrasion would combine to create maximal disturbance to benthic forms.

5.2.4.4 Iniskin Bay

Date: 8/24/76, about 0930
Elevation: MLLW to about +10 ft
Location: West and southwest side of Scott Island

Although both rock and sand substrates were present in the area examined, this effort was restricted to a cursory examination of the algae on the rocky substrate. Generally, the rocky areas were composed of bedrock; boulders and loose material were less common.

Algal cover was considerable; several species of brown, red and green seaweeds were abundant (Appendix B-8), but reds, particularly Rhodymenia palmata and Odonthalia sp. appeared to dominate. Fucus was abundant at the higher levels. Large laminarians were uncommon, a predictable consequence in higher intertidal levels. Many of the abundant species appear to be "pioneer" species, indicative of early stages of succession. These included the green filamentous alga Spongomorpha, the red algae Halosaccion glandiforme, Porphyra sp, Callophyllis sp., and Rhodymenia palmata. The curious brown alga Soranthera ulvoides, generally epiphytic, was abundant, particularly on Odonthalia sp.

The southwest end of the island appears exposed to waves off Kamishak Bay. Barnacles covered much of the available rock surface in the high intertidal there and appeared to compete strongly for space with Fucus and Halosaccion. Other observations on the fauna were not made, so

Table 12. Relative cover (%) of algal species observed in 1/4 m^2 quadrats from Rocky Point, Iniskin Bay, 8/24/76.

	Quadrats							
Species	1	2	3	4	5	6	7	$\bar{x} \pm s$ (%)
Callophyllis sp. (slender)	30	5	25	5	10	5	15	13.6 ± 10.3
Fucus distichus	10	25	30	75	40	10	35	32.1 ± 22.1
Laminaria spp.	0	5	0	0	0	0	0	0.7 ± 1.9
? *Monostroma* sp.	0	15	0	0	0	5	0	2.9 ± 5.7
Porphyra sp.	0	0	5	5	0	10	0	2.9 ± 3.9
Rhodymenia palmata	5	30	10	5	20	40	50	22.9 ± 17.8
Spongomorpha sp.	30	0	15	5	20	5	2	11.0 ± 11.0
TOTAL								86.1%

tropic dynamics cannot be discussed. However, the area appeared dominated by producers, and probably most of the plant material is exported to other areas for utilization.

5.2.5.1 Chinitna Bay

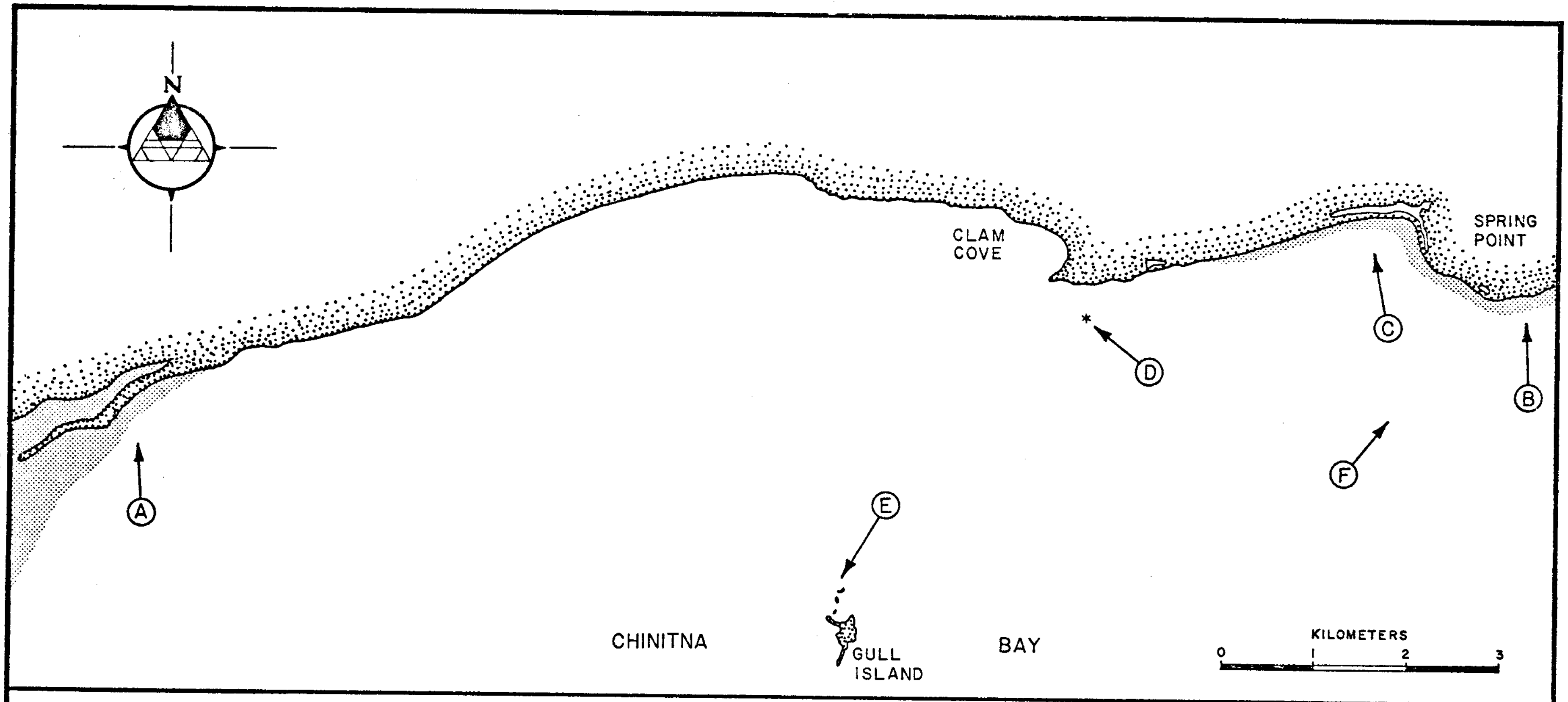
Date: 6/9 and 6/10/76 Tides: +1.9 feet at 1758 and +1.3 feet at 1852

Location: Glacier Spit; off W. Byers site

The Glacier Spit site is generally a protected habitat (Figures 1 and 17). The foreshore (above about +2 ft) is predominantly a moderately sloping gravel beach, devoid of animals. However, a large outcrop is located above MSL, and a few scattered boulders are located between +1 and +2 ft. The faunal assemblage on the upper outcrop was typical of its level, including the periwinkle *Littorina sitkana*, the blue mussel, and the barnacles *Balanus glandula* and *Chthamalus dalli*.

The fauna on the boulders at +1 to +2 ft was rather impoverished. Besides those species found higher, the sea anemone *Anthopleura ?xanthogrammica*, limpets, and the predatory snail *Nucella emarginata* were the principal species.

The main habitat in the area is a mud flat, which extends from about +2 ft on out into the subtidal portion of the bay. This flat has little slope. It is mainly a thin layer of unconsolidated fines overlaying a fairly well-consolidated clay. Visually, the flat is dominated by the filamentous brown alga *Pylaiella littoralis*, which, on low tide, forms a patchy thick brown scum on the substrate; relative cover is approximately 50%. The dominant macrofaunal forms were the soft shell clam *Mya ?arenaria* a small pink clam *Macoma balthica*, the spoonworm *Echiurus echiurus alaskanus* and the clam worm *Nephtys* nr *caeca*. The scaleworm ?*Hesperonoe* sp. and the



KEY:

(A) GLACIER SPIT MUD FLAT
(B) ROCKY INTERTIDAL BEACH, SPRING POINT
(C) BROWN SAND BEACH
(D) LOW INTERTIDAL ROCK REEF (CLAM COVE REEF)
(E) ROCKY INTERTIDAL – GULL ISLAND
(F) 1.7 KM SOUTHWEST OF SPRING POINT
TIDAL FLATS

CHINITNA BAY SITE

DAMES & MOORE

FIGURE 17

small clam Orobitella ?rugiferawere commonly observed associates of the spoonworm. Other common species were the burrowing anemone Anthopleura artemisia and the basket cockle Clinocardium nuttalli (Appendix B-9).

Biomass appeared moderately high, mainly as a result of the densities of Mya and Macoma, which appeared to be the more numerous animals on the flats (Table 13). Shell piles (fecal piles or egesta), probably left by surf scoters, indicate that utilization of Macoma balthica is quite high and that it forms an important proportion of the diet of that bird. Size data (Table 14) indicate that this small clam is mainly an annual and so its productivity is probably fairly high. Only adults were present in the population in June.

The trophic dynamics of this area appear rather simple. Herbivores were not observed and so it appears that the sparse algae do not directly contribute significantly to the system. The dominant organisms are divided between suspension and deposit feeders, and it appears that the major predators are transients such as fish or birds.

5.2.5.2 Chinitna Bay

Date: 6/11/76 Tide: -4.7 feet at 0734

Location: Beach 0.1 miles east of E. Glacier Creek

This site (Figure 17) is a moderately exposed beach with a gravel foreshore and a medium to fine sand lower beach. The moderately sloping foreshore was devoid of animals. The slope of the sandy lower beach, which extends from about MLLW into the subtidal, is rather gentle. The fauna was dominated by the razor clam Siliqua patula, for which density increased directly with distance below MLLW. The only large faunal forms

Table 13. Density of *Macoma balthica* and *Mya ? arenaria* on mudflats at Byers site, Chinitna Bay, 6/10/76

Macoma balthica in 78.5 sq. cm. corer	*Mya ? arenaria* in 1/16 sq. m. quadrat
11	7
10	9
15	14
21	18
15	4
7	3
	7
$\bar{x} \pm s$: 13.2 ± 4.9	2
No./ sq. m.: 1680	9
	15
	3
	5
	3
	4
	3
	2
	2
	3
	5
	$\bar{x} \pm s$: 6.2 ± 4.8
	No./sq. m.: 99.4

Table 14. Length frequency data for the clam *Macoma balthica*, Byers Beach, Chinitna Bay, 6/10/76

Shell length (mm)	Frequency	Percent
8	5	5.7
9	12	13.8
10	21	24.1
11	17	19.5
12	12	13.8
13	8	9.2
14	7	8.0
15	3	3.4
16	1	1.1
17	1	1.1

$n = 87$

$\bar{x} = 11.1$ mm.

$s = 2.0$ mm.

observed were clam worms (Nephtys nr caeca) and sand shrimp (Crangon alaskensis), both uncommon (Appendix B-10).

The micro-fauna was generally typical of the sand beaches, except for the apparent absence of phoxocephalid gammarids. Abundance was relatively low.

5.2.5.3 Chinitna Bay

Date: 6/10/76 Tide: -3.6 feet at 0645

Location: Rocky point about 0.5 mi. West of Spring Point and Gull Island upper intertidal

Observations of the rocky upper intertidal zone were made on Gull Island (Figure 1 and 17), in a bedrock-boulder habitat. Above MSL, the bedrock is rather steep and crumbly; in the spray zone, the lichens ?Caloplaca and ?Verrucaria, and the green algae Prasiola were common.

Lower down, between MSL and MLLW, the rock slope became more gentle and boulders were common. At about MLLW, the rock bench was moderately flat with several large shallow tide pools. Algae diversity and standing crop increased markedly through this zone. The dominant algae on the sloping bedrock and boulders were Halosaccion and Fucus. Littorina and Balanus glandula were not the most abundant animals. In tidepools on the bedrock bench, the seaweeds Pylaiella, Scytosiphon and Rhodymenia palmata were common; tiny hermit crabs and the sponge Halichondria were also common. The large sea anemone Tealia crassicornis was uncommon in the larger tidepools and channels (Appendix B-11).

Observations of the lower intertidal zone were made on an extensive boulder/bedrock area near Spring Point, on the north shore of Chinitna Bay

(Figure 17). This area is moderately exposed. The substrate near MLLW is composed of scattered large boulders and sand pockets. The biotic assemblage on the tops of rocks was dominated by the green algae Enteromorpha intestinalis and Ulothrix sp., the sponge Halichondria and barnacles; mainly a heavy set of young individuals dominated the sides. The green alga ?Monostroma was common around the bottom of the boulders, and extending out onto the surface of the sand pockets. The burrowing anemone Anthopoleura artemisia was common in these sandy areas (Table 15). The predatory snail Nucella emarginata was very abundant in certain areas and was feeding actively on barnacles in the moister areas. The bimodal size frequency distribution indicates at least two year classes (Table 16; Appendix B-11a). The limpets Collisella ?pelta and Notoacmea ?scutum were common.

In areas where boulders were more closely packed and sand pockets were uncommon, the red alga Rhodymenia palmata was common and limpets were uncommon.

Sand abrasion appears to be an important factor in determining whether red or green algae will dominate the flora in this location. Heavy abrasion probably occurs on the boulders resting in sand pockets, and precludes development of the algal assemblage past the pioneering green algae. This, in turn, probably has an influence on the abundance of limpets.

On the rocky bench between MLLW and -5 feet, algal diversity, cover, and biomass increased considerably. Laminaria groenlandica dominated the biota; both adults and juveniles were common (Table 16). Encrusting coralline algae, Callophyllis sp. and Rhodymenia palmata were also common.

The faunal assemblage also increased in diversity but no epifaunal species was very abundant (Table 17). Some of the more abundant

Table 15. Cover and density data for rock bench near MLLW, Spring Point, 6/10/76

ALGAE \ Quadrat*	1	2	3	4	5	6	$\bar{x} \pm s$	No. Per sq. m.
Fucus distichus	0	0	5%	5%	5%	0	2.5 ± 2.7%	
?*Monostroma* sp.	1%	0	15%	3%	0	0	3.2 ± 5.9%	
?*Polysiphonia* sp.	0	1%	0	0	0	0		
Rhodymenia palmata	0	0	0	15%	0	10%	4.2 ± 6.6%	
INVERTEBRATA								
Anthopleura artemisia	0	0	1	0	1	0	0.3 ± 0.5	1.3
Mya ?*truncata*	0	0	1	0	0	0		
Nucella emarginata	16	0	40	2	4	5	11.2 ± 15.2	44.7
Pagurus hirsutiusculus	0	0	0	1	0	0		

* 1/4 sq. m. square quadrat

Table 16. Shell length frequency data for the snail *Nucella emarginata* from Spring Point, 6/10/76

Size class (mm)	Frequency	Percent
12-15	1	0.5
16-19	5	2.5
20-23	28	13.5
24-27	16	8.0
28-31	42	21.0
32-35	72	36.0
36-39	30	15.0
40-43	6	3.0
44-47	1	0.5
n	201	
$\bar{x}$*	30.8 mm.	
s	5.8 mm.	

* $\bar{x}$ and s were computed from unclassed data in Appendix B-10.

Table 17. Cover and density data for low boulder bench, Spring Point; 6/10/76

ALGAE \ Quadrat*	1	2	3	4	5	$\bar{x} \pm s$	No. Per sq. m.
Alaria sp.	0	0	0	0	5%	1.0 ± 2.2%	
Callophyllis sp.	0	20%	20%	0	0	8.0 ± 11.0%	
Constantinea subulifera	0	0	1%	10%	0	2.2 ± 4.4%	
Corallina ? *vancouveriensis*	0	1%	20%	0	2%	4.6 ± 8.6%	
encrusting coralline alga	0	30%	8%	20%	15%	14.6 ± 11.4%	
?*Enteromorpha intestinalis*	15%	0	0	0	0	3.0 ± 6.7%	
Fucus distichus	5%	0	0	0	0	1.0 ± 2.2%	
Laminaria groenlandica (adult)	0	1;70%	2;80%	3;65%	6;75%	2.4 ± 2.3;58.0 ± 32.9%	9.6
L. groenlandica (juvenile)	0	8	0	5	4	3.4 ± 3.4	13.6
Ralfsia ? *pacifica*	0	0	0	2%	1%	0.6 ± 0.9%	
Rhodymenia palmata	10%	0	1%	15%	8%	6.8 ± 6.3%	
INVERTEBRATA							
Abietinaria gilicula	0	5%	1%	5%	1%	2.4 ± 2.4%	
Actiniaria, unid (burrowing)	0	0	1	0	0		
Balanus sp. (spat)	1%	0	0	0	0		
Caulibugula sp.	0	1%	0	0	0		
Henricia leviuscula	1	0	1	1	0	0.6 ± 0.5	2.4
?*Microciona* sp.	0	0	1%	0	0		
Mya ? *arenaria*	0	1	0	1	0	0.4 ± 0.5	1.6
Nereis sp.	0	0	1	0	0		
Tonicella lineata	0	1	0	1	0	0.4 + 0.7	1.6

* 1/4 sq. m. square quadrat

animals were the blood starfish Henricia leviuscula, the starfish Leptasterias hexactis and the green sea urchin Strongylocentrotus drobachiensis. The latter two species were invariably located under rocks; the sea urchins were exceptionally large and cryptic, indicating that sufficient drift algal material is available to provide for their food needs. They were probably not grazing directly on attached seaweed. Chitons were unusually successful here; five species were common (Appendix B-11).

Trophic dynamics are somewhat complex at the Spring Point location. Plant biomass was considerable, particularly below MLLW. An appreciable variety and abundance of herbivores was noted, including limpets, chitons and sea urchins. This indicates that plants probably contributed directly to the local energy pathways, but productivity probably far exceeds local consumption. A broad variety of suspension feeders, and a few deposit feeders were observed; both utilize main imported nutrients.

5.2.6 Polly Creek Beach

Date: 7/13/76 Tide: -3.7 feet at 0930
Location: Outer sand bars off Polly Creek

This beach is a moderately flat, broad brown sand bench (Figure 1). Shallow diagonal drainage channels intrude occasionally into the shoreline. Little physical difference was apparent between upper and lower tidal levels, although some variations in the relative coarseness of the sand were noted. Shell debris, mainly from large razor clams and redneck clams, is abundant, and seems to indicate a recent mass mortality.

Organisms were not observed above -1 foot. Except for razor clams, large and small infaunal forms were generally uncommon throughout the beach. Razor clams, however, were abundant, averaging over four clams per sq. m. (Table 18). Redneck clams (Spisula polynyma) were common and

Table 18. Density of the razor clam *Siliqua patula* at Polly Creek, 7/13/76

Number per 1/4 sq. m. quadrats*	Number of quadrats
0	26
1	23
2	9
3	4
4	2
5	0
6	1
Total	65

$\bar{x} \pm s = 1.03 \pm 1.21$ clams per 1/4 sq. m.

Estimated density: 4.12 clams/sq. m.

* based on counts of clam "shows" at sand surface.

much smaller than the shells observed in the debris (Appendix B-12).

Predictably, the trophic dynamics of this impoverished assemblage are very simple. Macrophytes and herbivores were absent, and the system was strongly dominated by suspension feeders such as *Siliqua*.

6.0 SUBTIDAL DIVE RECONNAISSANCES

Subtidal reconnaissances were conducted at several strategic locations using SCUBA techniques. A major objective of these dives was to examine the vertical distribution of seaweeds at various sites in Lower Cook Inlet in order to improve our ability to extrapolate on macrophyte distribution and primary production. Furthermore, it seemed that a comparison of the faunal assemblages in the nearshore regions would provide useful information.

A great deal of information is already available (Dames & Moore 1976, 1977) for the south side of Kachemak Bay. Therefore, the subtidal reconnaissances were restricted to the northern shelf in outer Kachemak Bay, and to Chinitna and Iniskin Bays on the west side of the Inlet. The description for the northern shelf area is adapted from an earlier report (Dames & Moore 1976).

6.1 Northern Shelf of Kachemak Bay

The north side of Kachemak Bay west of Homer Spit is a broad, rocky shelf. This relatively flat bench extends from Archimandritof Shoals, of the Spit, northwest to its broadest point Mutnaia Gulch and Anchor Point (Figure 18), a distance of approximately 20 miles.

The geological structures characterizing the shelf are fairly similar from east to west, except for an increase in the frequency of boulders and greater surface relief to the west. The physical and chemical characteristics of the water bathing the shelf appear to become markedly more oceanic in the vicinity of Mutnaia Gulch and Anchor Point. This is a consequence of the decreasing proximity to the estuarine conditions and glacial runoff at the east end of Kachemak Bay and the increasing proximity to the main stream of oceanic water flowing into Cook Inlet from the Gulf of Alaska.

Characteristic species were selected from the Kachemak Bay sites which were visited on several occasions. The index used (I) was based on the relative frequency of a species and its relative abundance and suspected importance at the site, where

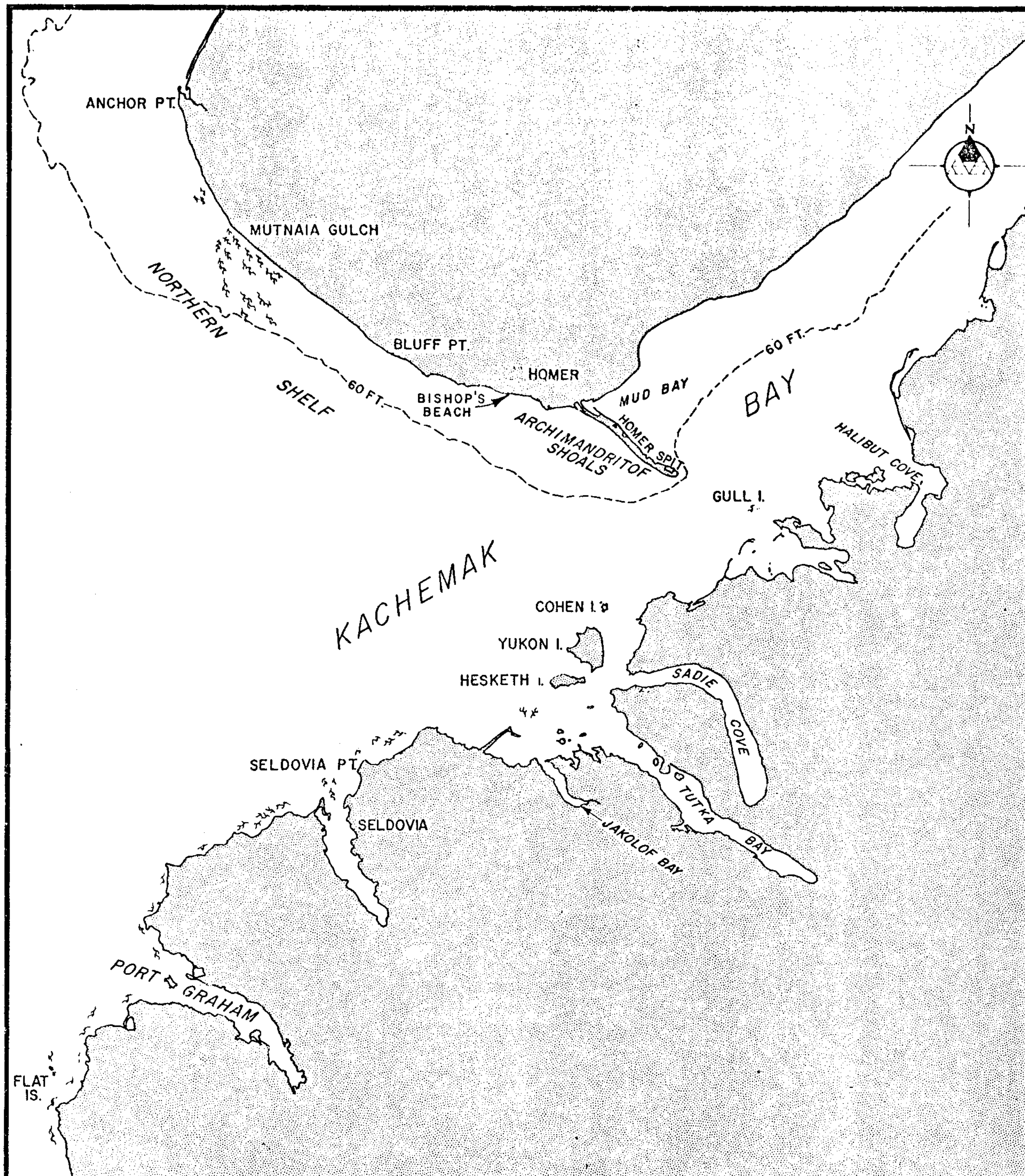
$$I = {}^{F}/N + C + 2A + 2^{D},$$

where F is the number of times the species was observed, N is the number of times the site was examined, C and A are the number of times the species was common or abundant, respectively, and D is the number of times the species was indicated as dominant. The intent of the equation is to rate the degree of importance ascribed to a species according to the frequency of occurrence and abundance at the site.

6.1.1 Archimandritof Shoals

The eastern end of the shelf area in Kachemak Bay (Figure 18) was examined at seven different sites ranging in depth from about 4 meters to about 8 meters below MSL. The bottom is a mosaic of cobbles, sand and shell debris. Small boulders of rock or coal are scattered throughout the area.

The benthic species most characteristic of the Archimandritof Shoals area (Table 19) include five species of algae, one macroherbivore, six suspension feeders, one scavenger, and two predators. Of the algae, only *Agarum cribrosum*, encrusting coralline algae, and *Laminaria groenlandica* are perennials. Generally, algal cover was substantially lower on Archimandritof Shoals than in the other areas of the Shelf. Sea urchins were



KACHEMAK BAY

DAMES & MOORE

FIGURE 19

very abundant despite the low algal standing crops. Among the suspension feeders, the horse mussel (<u>Modiolus</u>), a mat-forming polychaete (<u>Potamilla</u>), and the butter clam (<u>Saxidomus</u>) were very important. Horse crabs were the most consistently observed scavenger; however, horse crabs (<u>Telmessus</u>), juvenile tanner carbs (<u>Chionoecetes</u>), shrimp, and undoubtedly others are probably seasonally common. Additionally, the predators listed (<u>Fusitriton</u> and <u>Neptunea</u>) are probably both facultative scavengers, often taking advantage of prey species captured by predatory starfish. An important predator not included in Table 19 was the large starfish <u>Leptasterias polaris</u> var. <u>acervata</u>, which feeds heavily on pelecypods. Also, burrowing moon snails (<u>Natica</u> and <u>Polinices</u>) were important predators, especially on <u>Macoma</u> spp.

The species indicated above are characterizing Archimandritof Shoals are, in fact, only a small number of the organisms observed there. A more complete description of the biota in this area is presented in Appendices C-1 through C-1c, which report the composition and abundance data collected on each examination. More than 100 species were observed, including 13 species of algae, 12 crustaceans, 32 molluscs, and 11 echinoderms. Fish were generally uncommon and inconspicuous.

Several species that were inconspicuous, uncommon, or were not enumerated were nevertheless observed, and appeared to be reliable components of the faunal assemblage of the Shoal area. Species that were observed at least 50 percent of the time, but were not indicated as characteristic, include limpets (<u>Acmaea mitra</u> and <u>Cryptobranchia</u> sp.), a large barnacle (<u>Balanus nubilus</u>), a large solitary tunicate (<u>Halocynthia aurantia</u>), a serpulid polychaete (<u>Crucigera zygophora</u>), starfish (<u>Leptasterias polaris</u> var. <u>acervata</u> and <u>Crossaster papposus</u>), a moon snail (<u>Natica</u> sp.), a tubicolous polychaete (<u>Owenia fusiformis</u>), and chitons (<u>Tonicella insignis</u> and <u>T. lineata</u>).

Fully, one-quarter of the species observed in the area qualified as

Table 19. Characteristic benthic species on Archimandritof Shoals in order of calculated importance.

Species	Major Taxon	Trophic Category
Agarum cribrosum-P[1]	Brown alga	Producer
Strongylocentrotus spp.-p	Sea urchin	Herbivore
encrusting coralline algae-P	Red alga	Producer
Modiolus modiolus-P	Mussel	Suspension feeder
Fusitrition oregonensis-P	Snail	Predator
Neptunea lirata-P	Snail	Predator
Podoesmus macroschisma-P	Clam	Suspension feeder
Sertulariidae, unid, spp.-A	Hydroid	Suspension feeder
Pterosiphonia bipinnata-A	Red alga	Producer
Laminaria groenlandica-P	Brown alga	Producer
Paguroidea, unid, spp.-P	Hermit crab	Scavenger
Potamilla ?neglecta-P	Polychaete worm	Suspension feeder
? Cryptonemia sp.-A	Red alga	Producer
Flustrella gigantea-?	Bryozoan	Suspension feeder
Saxidomus gigantea-P	Clam	Suspension feeder

[1]P = perennial; A = annual

characteristic or were observed at least 50 percent of the time, indicating the relative homogeneity of the biota living on Archimandritof Shoals. This is partly a consequence of the fairly narrow depth range examined, but more important is the relative homogeneity of the physical environment and surface relief on the Shoals.

The trophic structure of the assemblage is moderately complex. Primary productivity in the area appears light, based on the algal standing crop. The large component of the algal stock was sieve kelp (Agarum cribrosum), for which densities up to 20/m^2 and coverage up to 45 percent were recorded. Encrusting coralline algae covered up to 75 percent of the hard substrate in some areas. Two annual or biannual red algae, ?Cryponemia sp. and Pterosiphonia bipinnata each contributed up to 10 percent cover. Two large kelps, Laminaria groenlandica and Nereocystis luetkeana, were generally uncommon, patchy in time and space. The latter formed a narrow bed about one mile long in 1974, but this had virtually disappeared by 1975 (R. Rosenthal, personal communication).

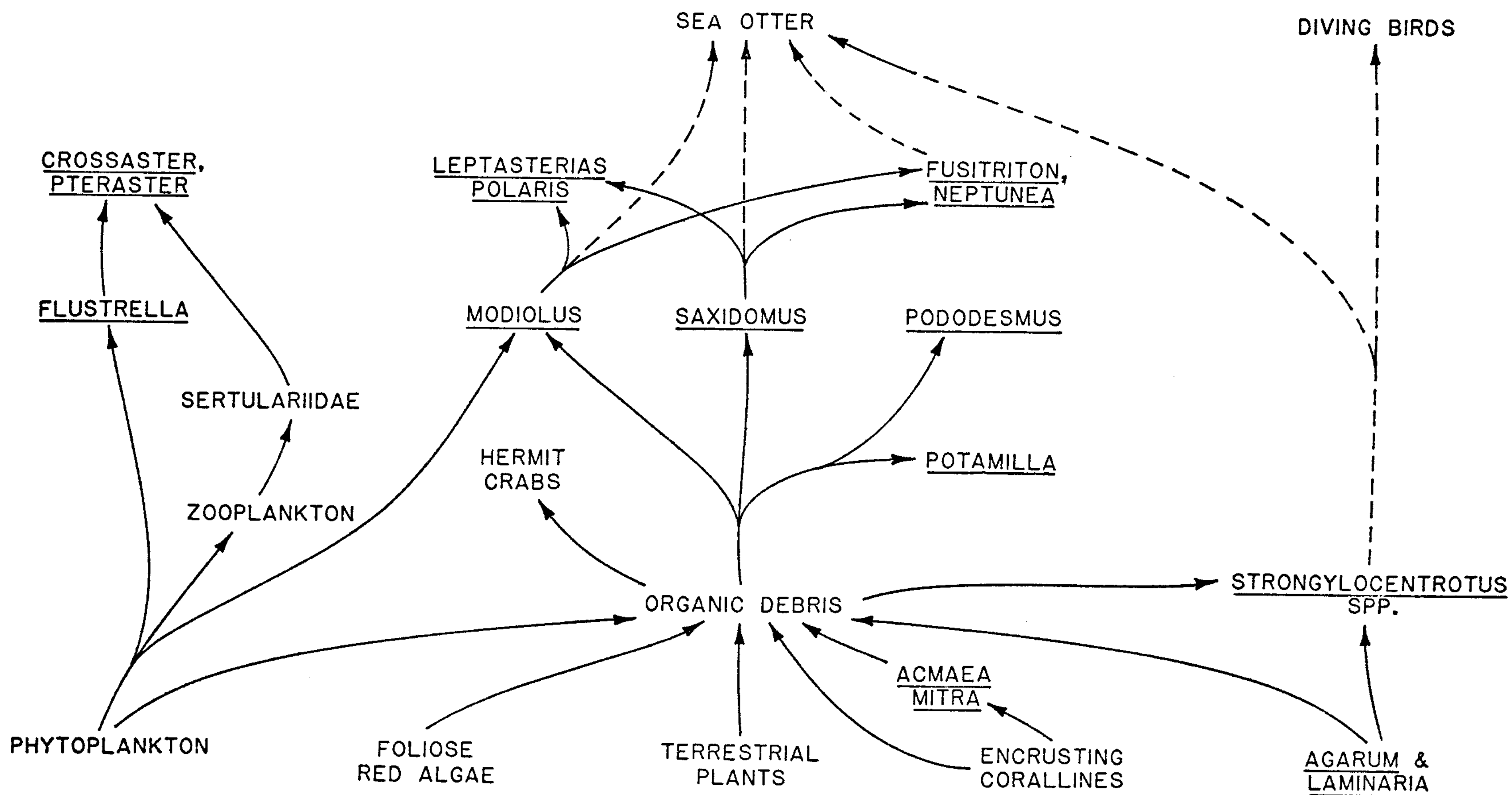
The area supports a broad suite of consumers and secondary productivity appears to be substantial. Most of the consumers are long-lived forms, and the populations are composed mainly of mature individuals. Only about 10 species of herbivore were recorded. However, in spite of the relatively light algal standing crop, the high abundance of macroherbivores (sea urchins) and microherbivores (Acmaea mitra and chitons) indicates that direct consumption of plant material is high. The most important were sea urchins of the genus Strongylocentrotus. The density of this group (S. drobachiensis, and S. pallidus, are combined because of the inability of satisfactorily distinguish between them in the field) ranged up to about 90 individuals/m^2, but probably averaged closer to 30/m^2. The populations comprised mainly adult individuals (Mean diameter = 40.0 $\pm$ 8.9 mm). The size distribution was unimodal (Appendix C-1d), suggesting that recruitment tothe population was slow. Grazers of lesser importance were the limpet Acmaea mitra and the chitons Tonicella insignis and T. lineata. When abundant, these forms are able to influence algal composition because they can graze off the gametophytes and sporelings of many algae, thus reducing their abundance. One plausible explanation for the poor development of the algal assemblage is overgrazing, particularly by sea urchins. Their exposed distribution indicates that the population is mainly browsing on attached algae rather than remaining cryptic and passively awaiting drift algae (Lees, 1970). This condition probably results from a relative undersupply of drift material. Based on these arguments, then, it is reasonable to suggest that primary productivity is somewhat higher than indicated by algal standing crop.

Of the more than 40 species of suspension feeders observed in the area, the horse mussel (Modiolus) and sabellid polychaetes (e.g., Potamilla ?neglecta), contributed the greatest standing crop in the area. Densities of horse mussels ranging up to 75 individuals/m^2 were observed (Appendix C-1c); a realistic average is probably closer to 30/m^2. The shell-lenth distribution was unimodal, but exhibited a wide range (19-127 mm); mean shell length was 72.1 mm. Assuming that the conspicuous concentric sculpture and pigment rings represent annular rings, many of the animals with shell lengths greater than 100 mm are more than 10 years old. Based on the suggested average density of 30 individuals/m^2, the size distribution indicated in Appendix C-1e and length-weight data from Bluff Point, the wet tissue weight of Modiolus averaged 845 g/m^2 (about 2 lbs/m^2) on Archimandritof Shoals. Sabellid polychaetes, mainly Potamilla ?neglecta, formed dense mats that consolidated large portions of the bottom. In several areas, over 50 percent of the bottom was covered by Potamilla; frequently, it was growing densely around Modiolus. In other areas, the butter clam (Saxidomus) and smaller Macoma inquinata were abundant associates of Modiolus. These species occupied a level in the substrate below the Modiolus bed, using their long siphons to communicate with the overlying water mass. Saxidomus densities in excess of 6/m^2 were observed.

Several species of suspension feeder escape the intense competition for suspended organics that such beds constitute by extending above the substrate into the water column. Examples of such forms on Archimandritof Shoals include hydroids, particularly of the family Sertulariidae, bryozoans such as *Flustrella gigantea*, and the tunicate *Halocynthia aurantia*.

About 35 species of scavenger and predator were observed. These included crustaceans, gastropods, starfish and fish. Characteristically, densities were low. The most numerous large predator/scavengers were the snails *Fusitriton oregonensis* and *Neptunea lirata*, with densities of up to $2/m^2$ and $3/m^2$, respectively. The average aperture length for *Fusitriton* was 41.5 mm, and the population mainly comprised older individuals, but insufficient data were collected to permit further comment on size structure (Appendix C-1f). Other important species were the starfish *Leptasterias polaris* var. *acervata* and *Crossaster papposus*, and the moon snail *Natica* sp. The combined densities of all these consumers produced a considerable standing crop of consumers, and indicate moderate secondary productivity.

Some idea of the complexity of the food web at Archimandritof Shoals can be obtained from Figure 19. The importance of organic debris to the system is quite obvious. In fact, all "transactions" effect either a contribution to or a utilization of the organic debris supply. This schematic, which deals primarily with interactions including the characteristic species, points out several loose ends. Foremost among these is the absence of information concerning predators for most of the herbivores and suspension feeders. The apparent absence of an effective predator for adult sea urchins is particularly notable (Appendix C-1g). This is particularly striking in view of the paucity of young urchins. Possible predators known to operate in this area are several species od diving birds. The general habit of this group of ingesting prey whole could act to create a size refuge for prey and may partially account for the size structure of the sea urchins.



FOOD WEB FOR THE CHARACTERISTIC SPECIES ON ARCHIMANDRITOF SHOALS

FIGURE 19

6.1.2 West of Bishops Beach, subtidal

Date: 8/3/76 Tides:

Location: 1.5 mi. southwest of Seafair Motel Depth: 14.6 m

A single reconnaissance dive was made at a location 11.5 meters below MSL on August 3, 1976, about 1½ miles southwest of the Seafair Motel (Figure 18). The substrate was cobble, small boulders and mud patches. The area was quite silty. The flora was dominated by ?*Opuntiella* sp. and *Rhodymenia pertusae*; brown algae were not observed (Appendix C-2).

Generally, the fauna was similar to that observed at Archimandritof Shoals. It was dominated by *Strongylocentrotus* spp., *Modiolus modiolus*, *Fusitriton oregonensis*, and *Neptunea lirata*. However, several species more identifiable with Bluff Point were observed, namely, the sponge *Suberites ficus*, the cockle *Serripes groenlandicus*, and the hermit crab *Pagurus* ?*confragosus*.

Size data were collected for four species to permit comparisons between different points on the shelf. The size distribution for *Strongylocentrotus* spp. was essentially unimodal with an average test diameter of 51.4 mm (Appendix C-2a). The paucity of specimens below 40 mm is peculiar. A similar pattern is apparent for the horse mussel (*Modiolus*; Appendix C-2b); the mean shell length for the unimodal distribution was 102.2 mm. By combining data from the size distribution and the length-weight regression established at Bluff Point, and using an estimated density of 15 mussels/m^2, the amount of west mussel tissue was estimated to be about 710 g/m^2 (about 1.5 lbs). Scanty data collected for the two large snails, *Fusitriton* and *Neptunea*, suggest that both populations were dominated by adults (Appendix C-2c).

Except for the absence of the large laminarian seaweeds, the trophic structure was similar to that described for Archimandritof Shoals. The major herbivore species, Strongylocentrotus spp., Tonicella spp., and Acmaea mitra were common, and several predator/scavengers were observed, namely, Fusitriton, Neptunea, Placiphorella, Pteraster, Leptasterias polaris var. acervata, Buccinum, Oregonia and several fish species. However, the fauna was dominated by suspension feeders, particularly Modiolus, Tresus capax, sertulariid hydroids, and sponges.

6.1.3 Bluff Point - Diamond Gulch Area

The mid-shelf area in the vicinity of Bluff Point and Diamond Gulch (Figure 18) was not examined during this study, but data are available from a previous study (Dames & Moore 1976). A brief description of the area is provided, based on those data.

Generally, the substrate is dominated by rock, but the habitat includes shell debris with boulder patches and outcrops, boulder and cobble fields, flat pavement, and patch reefs. Some of the reefs, outcrops and boulders are coal.

The benthic species most characteristic of the Bluff Point-Diamond Gulch area (Table 20) included four species of algae, one macroherbivore, six suspension feeders, one deposit feeder, and two predators. All of the algae were perennials and algal cover was frequently fairly dense, particularly at shallower levels. Sea urchins were the major herbivore. Among the suspension feeders, the bryozoans (Flustrella and Microporina, hydroids (particularly of the family Sertulariidae), and Modiolus were very important. The major predators listed (Fusitriton and Neptunea) are probably both facultative scavengers, often taking advantage of prey species captured by several species of predatory starfish that are not listed because of their low density. Nevertheless, several of these starfish, such as Evasterias troschelii, were important predators.

Table 20. Characteristic benthic species of Bluff Point-Diamond Gulch, in order of calculated importance.

Species	Major Taxon	Trophic Category
Alaria fistulosa-P[1]	Brown alga	Producer
Agarum cribrosum-P	Brown alga	Producer
encrusting coralline algae-P	Red alga	Producer
Fusitriton oregonensis-P	Snail	Predator
Strongylocentrotus spp.-P	Sea urchin	Herbivore
Laminaria groenlandica-P	Brown alga	Producer
Flustrella gigantea-?	Bryozoan	Suspension feeder
Neptunea lirata-P	Snail	Predator
Modiolus modiolus-P	Mussel	Suspension feeder
Microporina borealis-A	Bryozoan	Suspension feeder
Sertulariidae, unid. spp.-A	Hydroid	Suspension feeder
Maldanidae, unid.-P	Polychaete worm	Deposit feeder
Balanus nubilus-P	Barnacle	Suspension feeder
Henricia spp.-P	Starfish	? Suspension feeder
Pododesmus macrochisma-P	Clam	Suspension feeder

[1]P = perennial; A = annual

The species indicated above as characterizing the Bluff Point-Diamond Gulch area are, in fact, a very small number of the organisms observed there. A total of over 140 species was observed, including 14 species of algae, 9 sponges, 15 cnidarians, 19 crustaceans, 11 bryozoans, 35 molluscs, and 15 echinoderms. Fish, with 10 species, were moderately common.

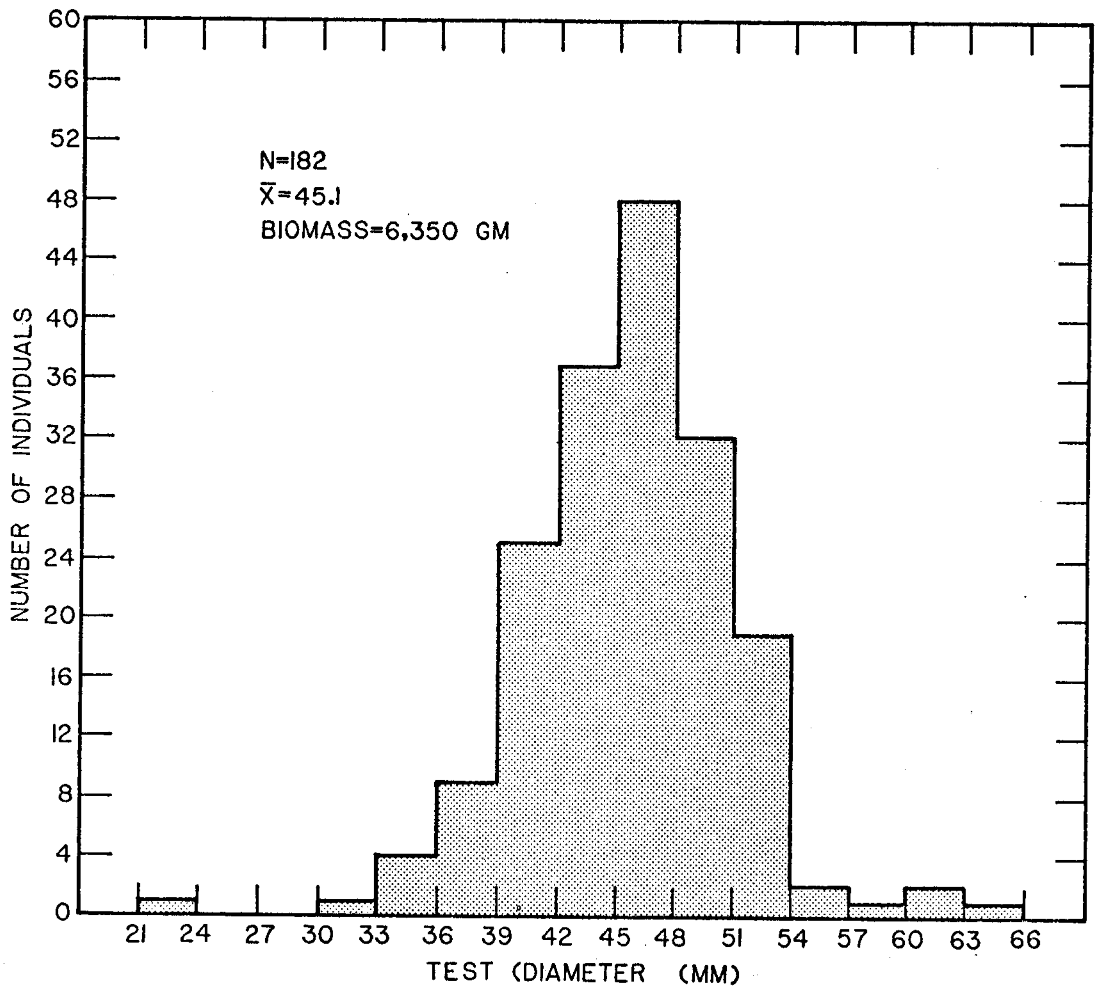
Several species that were inconspicuous, uncommon, or not enumerated were nonetheless frequently observed, and appear to be reliable components of the faunal assemblage. Species that were observed at least 40 percent of the time, but were not indicated as characteristic, include a limpet (*Acmaea mitra*), a small snail (*Trichotrophis cancellata*), two hermit crabs (*Elassochirus gilli* and *E. tenuimanus*), and three starfish (*Crossaster papposus*, *Evasterias troschelii* and *Lethasterias nanimensis*).

The number of species considered as characteristic or observed at least 50 percent of the time is an indication of the relative heterogeneity of the biota found in the Bluff Point-Diamond Gulch area. Only about 10 species (7 percent) occurred at half the stations and the combination of the characteristic species and additional inconspicuous species that were present at half the stations in only about 11 percent of the total species. Heterogeneity is also indicated by the variability in dominant species recorded for the area. At 10 stations where dominants were indicated, only one species (*Strongylocentrotus drobachiensis*) was dominant more than twice. The heterogeneity observed in this area is undoubtedly due partially to the diversity of habitats available, largely as a consequence of surface relief, and to the range of depths examined, but the physical parameters such as currents and turbidity are also quite variable.

The trophic structure of the biota is rather complex, partly because at least two assemblages are represented. Primary productivity in the area appears moderate, particularly because of the periodic occurrence of *Alaria* fistulosa. That kelp, although considered a perennial, is apparently sporadic and patchy. The several large beds observed in 1974 were not observed in this area in 1975 or 1976, although small patches did occur several miles to the west (R. Rosenthal, pers. comm.). Significant plant production appears restricted to rocky substrate shallower than 15 meters below MSL. Dominant algae in that depth range were Agarum, with up to 27 plants/m^2 and 45 percent cover; Laminaria, with at least 13/m^2; and encrusting coralline algae, with up to 75 percent cover. Other seaweeds that contributed appreciably to algal stocks were Desmarestia spp., Callophyllis sp., and Ptilota spp. It is probable that a considerable majority of the plant material produced in the area is not consumed directly by herbivores, but is either reworked locally, or is exported to other areas for later consumption by detritivores. The area supported a broad suite of consumers and secondary productivity appeared to be substantial. Most of the consumers were long-lived forms, and the populations were composed mainly of mature individuals.

Only about 10 species of herbivore were recorded. Macroherbivores (the sea urchins, Strongylocentrotus spp.) and microherbivores (A. mitra, Tonicella spp. and Cryptochiton) were numerous. The most important were sea urchins, for which density ranged up to about 29 individuals/m^2; average density was closer to about 5/m^2. The size distributions observed for sea urchins were basically unimodal (Figure 20); the average test diameter of about 44.5 mm is indicative of an adult population. The paucity of small individuals suggests that recruitment to the population is slow in this area.

The sea urchins in the Bluff Point-Diamond Gulch area were exposed and probably mobile, rather than cryptic and sedentary. As was noted for Archimandritof Shoals, this condition may indicate a relative undersupply of drift algae, which is generally a consequence of overpopulation. Such crowding is predictable at both Archimandritof Shoals and Bluff Point in view of the



SIZE DISTRIBUTION OF GREEN SEA URCHINS
REMOVED FROM A 1 X 5 M QUADRAT
APPROXIMATELY 2 MILES OFF DIAMOND RIDGE
AUGUST 27, 1974

DAMES & MOORE

FIGURE 20

paucity of such effective sea urchin predators as the sun star Pycnopodia helianthoides and sea otters.

Grazers of lesser importance were the limpets Acmaea mitra and Diodora aspera, the snails Calliostoma sp. and Lacuna sp., and chitons Tonicella spp. and Cryptochiton stelleri. It is possible that these species are sufficiently abundant to influence the flora appreciably in this area.

Over 60 species of suspension feeders were observed in the area, and some, such as Modiolus and the fleshy bryozoan Flustrella gigantea, contributed considerably to the biomass of the area. Densities of up to 57 mussels/ m^2 were recorded to Modiolus, but a more realistic overall average was probably closer to $15/m^2$. Average age of the animals probably exceeded 10 years, based on assumed annular rings, and many were over 17 years old. The shell-length distribution was strongly unimodal, ranging from 73 to 148 mm, and averaging 126.0 mm in length. Based on an estimated average density of $15/m^2$, the size distribution, and the shell-length-weight data collected in October 1975 (Appendices C-3 and C-3a), we computed an estimated wet tissue weight of 1,145 g/m^2 for the Bluff Point area. Table 21 shows the estimated biomass distribution for the area. Where the length-weight samples were collected, averge density was about $57/m^2$ and the estimated wet weight was about 4,350 g/m^2 (about 9.6 lbs).

Unfortunately, similar data are not available for other suspension feeders. Densities of up to 28 colonies/m^2 and 30 percent cover were recorded for Flustrella, but the average density and cover were probably far less. Colony heights of 15 cm were common, but no size or weight data were collected. Other important suspension feeders included the bryozoan Microporina borealis, sertulariid hydroids, and the rock jingle Pododesmus macroschisma.

About 50 scavenger and predator species were observed. These included

Table 21. Estimated distribution of wet tissue weight and biomass per sq.m. for _Modiolus modiolus_, collected from the subtidal zone west of Bluff Point*, 10/25/75.

Mean Shell Length of Size Class (mm)	Estimated Number of Individuals Per sq.m.*	Estimated Wet Tissue Weight (g) of Individual	Estimated wet Tissue Weight (g) Per Size Class
74	0.86	22.3	19.2
107	0.86	51.8	44.5
113	0.86	58.6	50.4
116	6.19	62.3	385.4
119	7.90	66.0	521.4
122	3.55	69.9	248.0
125	8.82	73.9	651.4
128	7.04	78.0	548.9
131	6.19	82.2	508.8
134	5.27	86.6	456.2
137	5.27	91.1	479.9
140	2.64	95.7	252.6
143	0.86	100.5	86.4
149	0.86	110.3	94.9
		Total wet tissue weight =	4347.5 g/sw.m. (9.58 lbs/sq. m.)

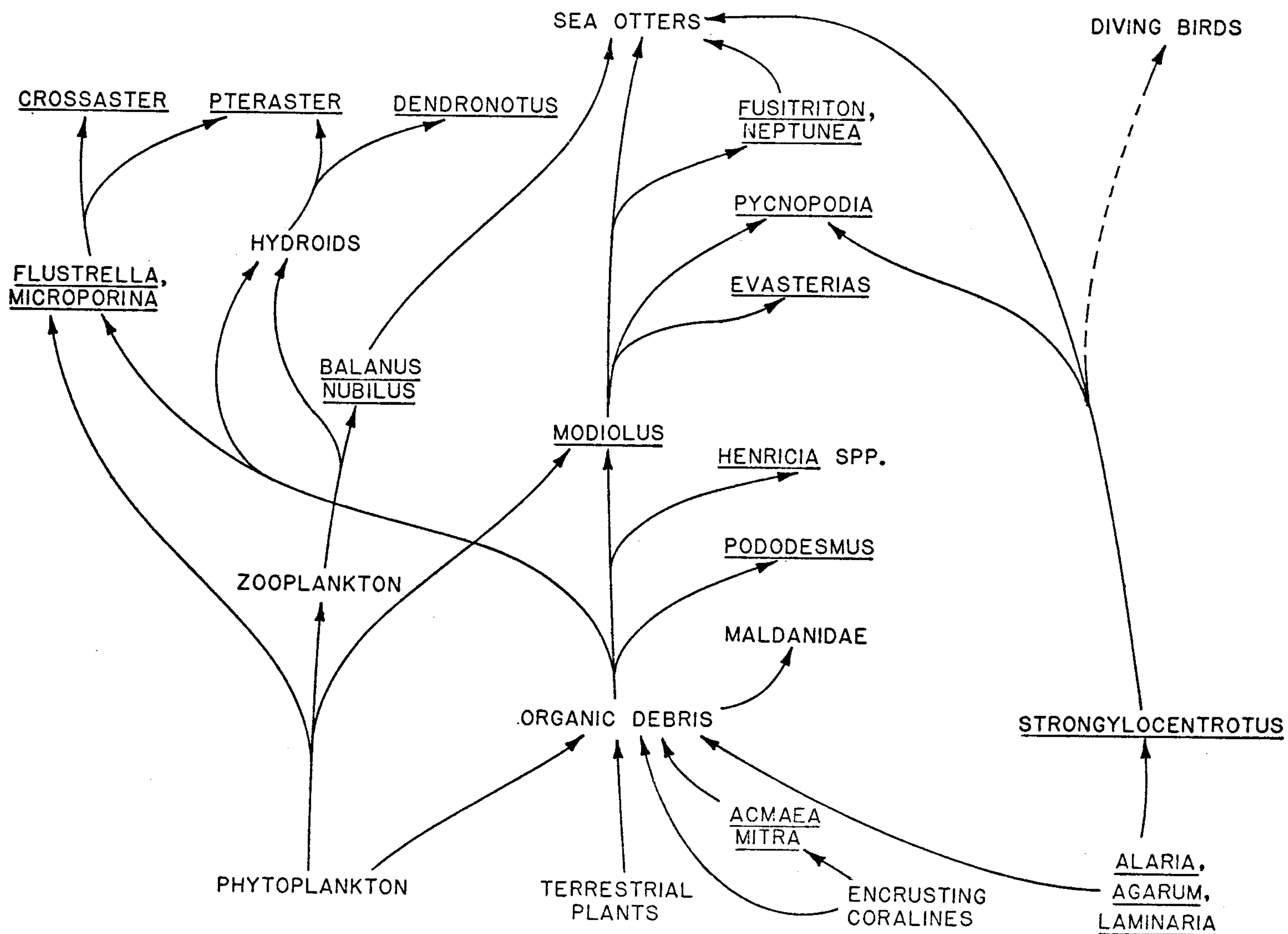
* Based on estimated density of 57.3 mussels/m^2

primarily crustaceans, gastropods, starfish and fish, as well as two sea anemones and a chiton. In some areas, densities and diversity of this trophic category were exceptionally high. For instance, at a 19.5 m station on a cobble/shell debris bottom, 15 of the 34 species noted were predators or scavengers, and most were large and common. The slender star (Evasterias troschelii), for example, averaged 1.4 individuals/m^2 and the average radius was 289 mm. Most of the trophic activity in this area revolved around the predatory activities of that star on Modiolus; several large snails, crabs and hermit crabs were observed "free-loading" at the banquets of Evasterias.

The two most numerous predators (or scavengers) overall were Fusitriton and Neptunea; densities up to 3.0/m^2 and 0.4/m^2, respectively, were recorded. The size distrubution of Fusitriton was basically unimodal; mean aperture length was 52.3 mm, indicating an adult population with apparently little recruitment.

Starfish and crustaceans were particularly diverse and important groups of predators. Ten species of predatory starfish were observed, of which five, including Crossaster papposus, Evasterias, Lethasterias nanimensis, Pteraster tesselatus and Solaster dawsoni, were common locally. Thirteen of the observed species of crustaceans are considered either predators or scavengers; eight of these were locally common. Particularly notable were the crabs Hyas lyratus and Oregonia gracilis, and the hermit crabs Elassochirus gilli, E. tenuimanus, Pagurus confragosus and P. ochotensis. Also, one-year old king crab were locally common at the deeper sites examined in this area.

The primary patterns of energy flow for the Bluff Point-Diamond Gulch area were very similar to those described for Archimandritof Shoals (Figure 21). Because of the basic faunal similarity, this is predictable. In this case, suspected major pathways were from the laminarian kelps to Strongyl-ocentrotus spp. and organic debris; from organic debris to Macoma, Saxidomus,



FOOD WEB FOR THE CHARACTERISTIC SPECIES
OFF THE BLUFF POINT–DIAMOND RIDGE AREA

FIGURE 21

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Modiolus, Flustrella and sponges; from phytoplankton to Modiolus and zooplankton. Not shown in Figure 21 are the linkages for all categories to a scavenger/ predator group that includes most of the Crustacea. This linkage is very poorly understood in these assemblages but quite important in several respects. First, many of the crustaceans are commercially important and, furthermore, utilize the shelf for a nursery ground. Second, many of these crustaceans are commercially important food items for important sport and commercial fish species such as salmon and halibut.

6.1.4 Anchor Point - Troublesome Creek Area

The western end of the northern shelf area, in the vicinity of Anchor Point and Troublesome Creek (Mutnaia Gulch), is the widest, and generally shoalest, portion of the shelf (Figure 18). It was examined at 5 locations, ranging in depth from 9 to 18 meters. At all locations, the substrate was rocky and large reef systems were common; cobble and shell debris were also important components of the substrate. The reefs imparted moderate surface relief to the bottom.

The dominant species at each station varied widely (Appendix C-4). The benthic species most characteristic of the area (Table 22) included four species of algae, two herbivores, seven suspension feeders and two predators. Only two of the seaweeds were perennials. Sieve kelp (Agarum) was the only important laminarian; the other species were small and ephemeral, or encrusting; algal cover and biomass were fairly light. Sea urchins (Strongylocentrotus spp.) were extremely important macro-herbivores, and the chitons Tonicella insignis and T. lineata were important microherbivores. Among the suspension feeders, the large sea cucumbers Cucumaria miniata and C. ?fallax were very important. Several other important forms were the fleshy bryozoan Flustrella, several hydroids of the family Sertulariidae, the butter clam (Saxidomus gigantea), a giant acorn barnacle Balanus nubilus,

Table 22. Characteristic benthic species off Mutnaia Gulch - Anchor Point in order of calculated importance.

Species	Major Taxon	Trophic Category
Strongylocentrotus spp. - P*	Sea urchin	Herbivore
Cumcumaria miniata - P	Sea cucumber	Suspension feeder
Desmarestia ligulata - A**	Brown alga	Producer
encrusting coralline algae - P	Red alga	Producer
Flustrella gigantea - ?	Bryozoan	Suspension feeder
Tonicella spp. - P	Chiton	Herbivore
Agarum cribrosum - P	Brown alga	Producer
Sertulariidae, unid, spp. - A	Hydroid	Suspension feeder
Henricia spp. - P	Starfish	Various with species
Saxidomus gigantea - P	Clam	Suspension feeder
? Opuntiella sp. - A	Red alga	Producer
Balanus nubilus - P	Barnacle	Suspension feeder
Cucumaria ? fallax - P	Sea cucumber	Suspension feeder
Halichondria sp. - P	Sponge	Suspension feeder
Evasterias troschelii - P	Starfish	Predator

* P = perennial

** A = annual

and an encrusting sponge Halichondria sp. Major predators were starfish (Henricia spp. and Evasterias).

The species listed above are characterizing the Anchor Point-Troublesome Creek biota are only a small proportion of the organisms observed there and, because of the diversity of the biota and the heterogeneity of the substrate and assemblages, produce a very incomplete description of the area. A more complete description of the biota is provided in Appendix C-4, which reports the composition and abundance data for each station. A total of over 100 species was observed, including 11 species of algae, 7 sponges, 9 cnidarians, 12 crustaceans, 25 molluscs, and 17 echinoderms. Fish, with 8 species, were in fact common, and the area had the greatest diversity of demersal fish observed in Kachemak Bay. These totals are unquestionably too low, however, based on the number of sites examined and the taxonomic difficulties. A large number of species were not recognized and thus unspecified.

Several species that were inconspicuous, uncommon, or were not enumerated were nonetheless frequently observed, and appear to be reliable components of the faunal assemblage. Species that were observed at least 50 percent of the time, but were not indicated as characteristic, included two brown algae (Desmarestia viridis and Laminaria groenlandica), a limpet (Cryptobranchia concentrica), a chiton (Cryptochiton stelleri), a small crab (Cancer oregonensis) a brittlestar (Ophiopholis aculeata), two starfish (Crossaster papposus and Pteraster tesselatus) and four fish (Irish lord, northern ronquil, and the rock and whitespotted greenling). Over half of these predators.

About 25 percent of the species were observed at least 60 percent of the time, suggesting moderate homogeneity. However, this is not consistent with the opinion of the investigators. In fact, this area is one of the most robust, diverse faunal assemblages observed in Kachemak Bay or the Gulf of Alaska, but it has not been adequately sampled. Its flora and fauna differ markedly from those of all other areas surveyed. Many important groups (e.g., sponges, hydroids, and sea anemones) could not be properly described because of their taxonomic complexity and time constraints. At least 10 species of hydroids are included under the category Sertulariidae, unid, spp., and most were very common.

The variability in the dominants noted for the stations (Appendix C-4) is a valid indication of the heterogeneity of the area, and also illustrates the peculiar nature of the biota. For the 5 stations occupied, 10 species were designated as dominants, and only 3 (Cucumaria ?miniata, Desmarestia ligulata and encrusting coralline algae) were dominant more than once; furthermore, half of those dominants were generally uncommon or absent in the other areas examined on the north shelf.

The trophic structure of the biota was rather complex, partly because it probably represented at least two assemblages. Primary productivity in the area was probably fairly light. The dominant algae were Desmarestia ligulata, with up to 35 percent cover, encrusting corallines, with up to 40 percent cover, and ? Opuntiella sp., with up to 45 percent cover The smaller laminarians (Laminaria and Agarum) were only locally common. Maximum density and cover for the former were 1/2 m^2 and 10 percent, respectively. Agarum was reported dominant at one station but not quantified (Appendix C-4). Macroherbivores (sea urchins) and micro-herbivores (especially Tonicella spp. and Cryptochiton stelleri) were numerous. It is probable, however, that a considerable proportion of the plant material produced in the area is not consumed directly by local herbivores, but is either reworked locally before consumption by suspension feeders or is exported to other areas for later consumption by detritivores.

The area supports a broad suite of consumers and secondary productivity appears considerable. In fact, a possible reason for the light plant production is the apparently intense copetition for suitable substance between plants and encrusting animals. This is particularly apparent in the relatively low coverage figures for the encrusting corallines (Appendix C-4). Most of the consumers are long-live forms and the populations are mainly composed of mature individuals.

Only about 9 species of herbivores were recorded. The most important were the sea urchins, for which density ranged up to about $38/m^2$; an average density of about $5/m^2$ over the entire area is probably more realistic. The size distributions observed for sea urchins were basically unimodal, with average test diameters ranging from 37.3 mm to 47.6 mm (Appendices C-4a through C-4c). The apucity of small individuals suggests that successful recruitment to the population has been slow in this area. It is doubtful that the less important grazers have had a notable influence on the floors.

Over 35 species of suspension feeders were observed in the area, with some, such as the sea cucumbers, the fleshy bryozoan _Flustrella_ and the encrusting sponge _Halichondria_ sp., contributing heavily to the biomass of the area. Densities of up to $14.6/m^2$ and $1.2/m^2$ were recorded for _Cumcumaria miniata_ and _C. ?fallax_, respectively; more realistic average densities for these species were probably $10/m^2$ and $0.5/m^2$, respectively. Both species probably exceeded an average of 250 g wet weight per individual. Coverage by the bryozoan _Flustrella_ was about 7 percent at one station, and although noted as common and abundant at two other stations, not quantified elsewhere. The thick encrusting sponge _Halichondria_ sp. was so abundant as to be considered as a dominant at one station, where it covered over 50 percent of the high relief surfaces; although not indicated specifically, it was undoubtedly common at several of the other stations. Other locally important suspension feeders included hydroids of the family Sertulariidae and Eudendrium vaginatum, the horse mussel Modiolus, and the butter clam Saxidomus. The shell length distribution for Modiolus was possibly bimodal, with a range from 68 to 117 mm, and a mean of 97 mm; confidence in the shape of the distribution is lessened by the small sample size (Appendix C-4d). Based on this size distribution, an estimated overall density of 10 individuals/m^2 (Appendix C-4e), and the length-weight regression from Bluff Point, the estimated biomass of Modiolus was around 430 g of wet tissue/m^2.

About 40 species of scavengers and predators were observed in this area. These included primarily crustaceans, gastropods, starfish and fish, although three species of sea anemone were included. The most conspicuous predators were the starfish Crossaster and Evasterias, each with densities up to about 0.03/m^2 (Appendix C-4f). Average size of Evasterias was large (Appendix C-4g). Another common star was Henricia sanguinolenta, which appeared to be feeding on sponges. However, because of difficulty in field recognition, density data are suspect.

Abundance of fish was not quantified, but they constitute an important group of predators in this area. Fish were more abundant and diverse than at other locations, and many of the cottids and greenling were rather large. Furthermore, because of its location, large numbers of salmon probably feed in this area during their summer migrations up the Inlet.

As a consequence of similar trophic structures, the basic patterns of energy flow for the Anchor Point-Troublesome Creek area were very similar to those described for Bluff Point and Archimandritof Shoals. The details of the species involved may vary somewhat with location, but the systems basically revolved around utilization of organic debris by suspension feeders (Figure 22). In this case, suspected major pathways were from laminarian kelps and other seaweeds to _Strongylocentrotus_ spp. and organic debris, from phytoplankton to _Modiolus_ and zooplankton.

Linkages from all categories to a scavenger/predator group that includes most of the Crustacea are not shown in Figure 22 or indicated in Appendix C-4). This linkage is very poorly understood, but is quite important in several respects. First, many of the crustaceans are commercially important (in this area, dungeness and probably king crab) and, furthermore, utilize the shelf area for a nursery ground. Second, many of these crustaceans are important food items for valuable sport and commercial fish species such as salmon and halibut. As pointed out earlier, this may be particularly true for salmon in this area.

6.2.1.1 _Iniskin Bay_

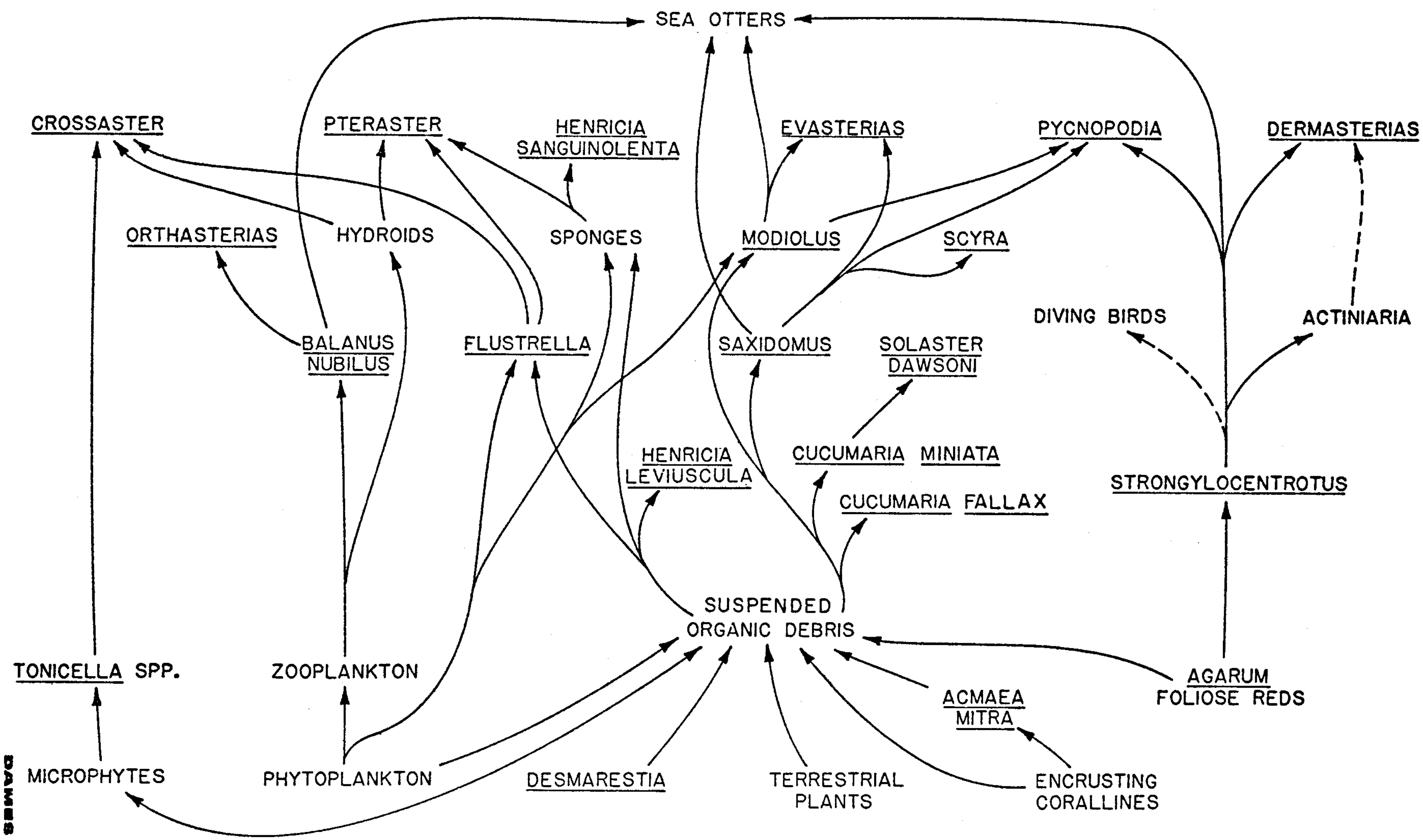
Date: 8/23/77, 1215-1315 Tide: about 14.7 feet at 1330 at Nordyke Island

Actual Depth: 18 to 15 feet

Corrected Depth: 3 to 0 feet below MLLW

Location: about 300 yards northeast of Iniskin Rock

The subtidal area observed northeast of Iniskin Rock (Figure 16) was mainly bedrock with scattered boulders and patches of shelly sand. Much of the rock was exposed and bare. The boulders were generally solidly fixed to the substrate. Most of the area examined is probably exposed during extreme low tides. As a consequence of this and the exposure of the area to waves, little silt was observed on rock surfaces.



FOOD WEB FOR THE CHARACTERISTIC SPECIES
OFF THE ANCHOR POINT–TROUBLESOME CREEK AREA

DAMES & MOORE

FIGURE 22

The biota at the deeper levels was visually dominated by the kelps Laiminaria groenlandica and Alaria ?marginata (Appendix C-5). Macrophyte cover was considerable. Laminaria was most important (Tables 23 and 24). Other important fleshy species included Constantinea subulifera, Corallina sp., and Odonthalia kamschatica. A number of other less important algal species was observed. Encrusting coralline algae formed on conspicuous veneer, covering nearly 50% of the rock surfaces (Table 24).

In the shallower rocks, the most conspicuous forms were Odonthalia kamschatica, Porphyra sp., Halosaccion glandiforme and Pterosiphonia bipinnata (Table 24). Encrusting corallines were again conspicuous.

Several species of herbivore were observed. Microherbivores were diverse and numerous. The chiton Tonicella lineata was the most abundant of these (Table 24), but acmaeid limpets were also common. Several other chiton species, including Katharina tunicata, were observed (Appendix C-5). The only macroherbivore observed was the green sea urchin Strongylocentrotus drobachiensis, which was cryptic and uncommon. Average test diameter was small.

The suspension feeding assemblage exhibited rather poor development. The dominant form was a large sea mussel, Modiolus modiolus, generally located in the lower level examined, among the Laminaria. Other forms included sponges, polychaetes, barnacles and bryozoans, but none were particularly important (Table 24, Appendix C-5). However, the small holothurian Eupentacta ?quinquesemita was common but cryptic.

The predator/scavenger assemblage was also poorly developed. Large sea anemones, crabs, snails and starfish were generally uncommon.

Table 23. Abundance of dominant macrophytes 300 yards NE of Iniskin Rock, 8/23/76.

Quadrat[a]	Number of plants per quadrat: *Laminaria groenlandica*	*Alaria marginata*
1	13	8
2	130[b]	19
No./m^2	14.3	2.7

Substrate: Rock

[a]Quadrats were 1 x 5 m

[b]Mostly juveniles

Table 24. Relative cover (c) and abundance of species observed in 1/4 m^2 quadrats from NE of Iniskin Rock, Iniskin Bay, 8/23/76

Species	1	2	3	4	5	6	7	$\bar{x} \pm s$	Density No./m^2
Alaria marginata (C)*	0	10%	10%	10%	25%	10%	3%	9.7 ± 7.9%	
A. marginata	0	0	0	0	1	2	2	0.7 ± 1.0	0.5
Constantinea subulifera (C)	40%	20%	5%	0	0	5%	0	10.0 ± 15.0%	
Corallina sp. (C)	0	1%	20%	5%	0	0	10%	5.1 ± 7.5%	
Encrusting coralline alga (C)	35%	50%	65%	50%	60%	10%	40%	44.3 ± 18.4%	
Halosaccion glandiforme (C)	0	0	0	2%	0	2%	10%	2.0 ± 3.7%	
Laminaria groenlandica (C)	100%	80%	75%	75%	25%	70%	15%	62.9 ± 30.9%	
L. groenlandica (adult)	1	0	2	8	7	20	0	5.4 ± 7.2	3.1
L. groenlandica (Juvenile)	0	11	17	**	-	-	-	4.0 ± 7.0	2.3
? *Monostroma* sp. (C)	0	0	0	2%	0	0	0	0.3 ± 0.8%	
Odonthalia kamschatica (C)	0	5%	5%	5%	25%	5%	0	7.9 ± 12.2%	
Pterosiphonia ?bipinnata (C)	0	10%	0	0	0	5%	5%	2.9 ± 3.9%	
Porphyra sp. (C)	0	0	0	0	0	0	15%	2.1 ± 5.7%	
Phycodrys sp. (C)	0	0	0	2%	0	0	0	0.3 ± 0.8%	
Ralfsia pacifica (C)	0	0	2%	0	0	0	0	0.3 ± 0.8%	
Rhodymenia palmata (C)	0	0	0	0	0	2%	0	0.3 ± 0.8%	
Abietinaria inconstans (C)	0	1%	0	-	-	-	-	0.3 ± 0.6%	
Balanus balanus pugettensis (C)	0	0	5%	-	-	-	-	1.7 ± 2.9%	
Cirripedia spat	P	0	0	-	-	-	-		
Hymendectyon lyoni (C)	0	5%	4%	-	-	-	-	3.0 ± 2.6%	
Modiolus modiolus	6	23	10	-	-	-	-	13.0 ± 8.9	17.3
Mopalia ? ciliata	0	1	0	-	-	-	-	0.3 ± 0.6	0.4
Natica clausa	0	0	1	-	-	-	-	0.3 ± 0.6	0.4
Halichondria panicea (C)	2%	0	0	-	-	-	-	0.7 ± 1.2%	
Plumularia setacea (C)	0	0	1%	-	-	-	-	0.3 ± 0.6%	
Tonicella lineata	3	3	8	-	-	-	-	4.7 ± 2.9	6.2
Depth (ft):	18	18	18	16	16	16	16		
(m):	5.5	5.5	5.5	4.9	4.9	4.9	4.9		

* indicates percent cover
** indicates data were not collected on species

No adult starfish were observed. The only common predator observed was the white-spotted greenling (Appendix C-5).

A wide range of organisms was observed in this area but the trophic structure was rather simple. With but few exceptions, consumer species were not abundant and so it appears that only a small amount of food material is used in the area. Suspension feeders were probably the dominant feeding types. Plant production appeared moderate and the area was probably primarily an export system. The nature and location of the sedentary species suggests that ice scour may be an important factor in this area. The notion is amplified by the preponderance of juvenile laminarians and pioneer algal species and the virtual absence of adults of arge invertebrates such as starfish, hermit crabs and snails.

6.2.1.2 Iniskin Bay

Date: 8/23/76, 1350-1430 Tide: about 14.7 feet at 1330 at Nordyke Island

Actual Depth: 30 feet below water surface

Corrected Depth: 15 feet below MLLW

Location: Outside entrance of Iniskin Bay, about 200 yds. south of Iniskin Rock The subtidal area observe

The subtidal area observed south of Iniskin Rock (Figure 16) was mostly cobble with large pockets of shelly silt. Shell debris was an important component of the substrate and boulders up to 4 feet in diameter were scattered through the area. A moderate quantity of drift algae was observed in the area.

The biota was strongly dominated by suspension feeding organisms, particularly barnacles, encrusting bryozoans and sponges (Appendix C-6).

The cobbles and boulders were extremely jagged and rough as a consequence of the heavy encrustation of Balanus rostratus alaskanus and various encrusting bryozoans. The barnacles were of medium to large size. Most were heavily encrusted with red, tan, orange and brown bryozoans, including Costazia ventricosa, Parasmittina sp. and ?Rhamphostomella sp. The most abundant sponge was yellow with a pebbled surface. It covered the entire exposed surface of some boulders. The ubiquitous Halichondria panicea was also common. Several other species of bryozoans common in the area included the fleshy lobed Alcyonidium ?pedunculatum, the thin lobate Carbasea carbasea and Terminoflustra membranaceo-truncata. Two hydroid species, Sertularia cupressoides and Thuiaria cylindrica were common. Sabellid polychaetes Potamilla spp. and Sabella crassicornis) were common. The most common suspension feeding mollusc was the pelecypod Hiatella arctica.

Several seaweeds were observed in the area but all species were uncommon (Appendix C-6). Algal cover was very sparse. Even encrusting forms were sparse. No species appeared to dominate.

Several herbivore species were observed. The most important macroherbivores were sea urchins of the genus Strongylocentrotus. Density was higher than indicated in Table 25. The average size of the individuals was very large (Appendix C-6a) and the population appeared reproductively mature. These factors create the impression that the population has adequate food. Chitons were the dominant microherbivores (Appendix C-6); Tonicella lineata was most common.

Numerous scavenger and predator species were observed in the area. Hermit crabs were abundant and the group was diverse; Elassochirus gilli was most abundant. Two important snails were Fusitriton oregonensis and Neptunea lyrata. Fusitriton density was highest (Table 25). The

Table 25. Density data for several macroinvertebrates from south of Iniskin Rock, Iniskin Bay, 8/23/76

	25x1m	10x1m	5x1m	Density (no./m^2)
Crossaster papposus	1	0	0	0.025
Fusitriton oregonensis	-*	3	5	0.53
Leptasterias polaris acervata forma *acervata*	14	2	3	0.48
Neptunea lyrata	-	1	0	0.07
Strongylocentrotus drobachiensis	-	1	0	0.07
Depth (ft)		26	26	
(m)		7.9	7.9	
Substrate		Cobble	Cobble	

* - indicates species was not surveyed

average size of the individuals was large (Appendix C-6b). Starfish were the most common predator observed in the area, but species diversity was low. Most important among these was the large Leptasterias polaris var. acervata (Table 25); Average radius of Leptasterias was 113.0 mm (Table 26); the population exhibited a bimodal size structure. The density of Crossaster papposus was higher than indicated by the data in Table 25; the average radius of 49.8 mm indicates that the individuals were large. (Appendix C-6a). White spotted greenling were common in the area.

Several feeding observations were recorded (Table 27). Leptasterias was most active, feeding on barnacles and soft shell clams. Also Crossaster was observed feeding on the fleshy bryozoan Alcyonidium ?pedunculatum.

Trophic dynamics were fairly complex but the area was nevertheless dominated by suspension feeders, which competed strongly for space. Drift algal material and suspended organic debris were important food materials. Local plant production was probably too low to support the local macroherbivores, but grazing undoubtedly was an important factor in the paucity of attached algae. Other factors that were probably important in this area were turbidity and competition for space by suspension feeders. Based on the apparently low level of plant production and the abundance of herbivores and suspension feeders, the assemblage at this location must be an import system, depending mostly on food materials originating in other locations.

6.2.1.3 Iniskin Bay

Date: 8/24/76, 1245-1315 Tide: +13.9 ft
Actual Depth: 24 ft deep Corrected Depth: 10 ft below MLLW

Table 26. Maximum radius data for the starfish *Leptasterias polaris* var. *acervata* from south of Iniskin Rock, Iniskin Bay, 8/23/76

Maximum radius (mm)	Frequency	Percent
70-74	1	1.9
75-79	2	3.8
85-89	0	0
90-94	0	0
95-99	1	1.9
100-104	9	17.0
105-109	4	7.5
110-114	9	17.0
115-119	8	15.1
120-124	2	3.8
125-129	8	15.1
130-134	4	7.5
135-139	3	5.7
140-144	1	1.9
145-149	1	1.9

$\bar{x} \pm S$	113.0 $\pm$ 20.7 mm
n	53

Table 27. Feeding observations for Rocky Point and south of Iniskin Rock in Iniskin Bay, 8/23/76

Predator	Prey	No. of Observations	Type of Observation
Crossaster papposus	Alcyonidium ?pedunculatum	1	direct
Leptasterias polaris var. acervata	Balanus sp.	7	"
	Mya sp.	3	"
	Pectinaria granulata	1	"
Aeolidida, unid.	Hybocodon prolifer	1	"

Location: about 200 yards west of Rock Point, by Blackie Cove

The bottom examined in this area (Figure 16) was a rather sticky, consolidated clayey silt with shell debris and scattered cobble common. The substrate surface is regularly swept by moderate tidal currents. Organic debris, particularly algal fragments, was fairly common. The major component of algal debris was the brown Laminaria groenlandica. A few specimens of this species, attached to cobbles, were observed in the area.

The biota was dominated by suspension feeders. Most of these species were burrowers such as clams and tubicolous polychaetes, but hydroids and bryozoans were surprisingly abundant, attached to both cobbles and shell debris (Appendix C-7). Dominant suspension feeders included the clams Mya spp., Clinocardium nuttallii and Macoma spp. Other common forms were the hydroids ?Hybocodon prolifer and Thuiaria cylindrica, a sabellid polychaete Potamilla sp. 2, a barnacle Balanus balanus, and the bryozoans Alcyondium ? penduncvlatum and Carbasea carbasea (Appendix C-7).

Undoubtedly, deposit feeders such as the clams Nuculana and Yoldia are also important in the area. However, most species of this guild are not obvious during visinspections, especially on silty substrates where excavation is not practical. Therefore, the composition and importance of this assemblage has probably been underestimated.

The predator/scavenger assemblage was not well developed, but four species were common. The large starfish Leptasterias polaris var. acervata dominated; its density averaged about 0.7 individuals/m^2 (Appendix C-7). The average radius of 76.8 mm indicates a mature population. Although the data are scanty, the population may be bimodal (Appendix C-7a).

Juveniles about 15 mm in diameter were obsered. Other common members of this guild included a whelk Neptunea lyrata, a hermit crab Pagurus beringanus, an unidentified aeolid nudibranch, and the white-spooted greenling Hexagrammos stelleri.

The assemblage observed in this location had low species diversity in comparison with nearby rocky areas, but was fairly complex for a soft substrate biota. The trophic dynamics were not very complex but all major trophic categories were present. Although some plant material is produced in the area, most of food materials are probably imported from other, more productive areas to support the dominant detritus consuming assemblages.

6.2.2.1 Chinitna Bay

Date: 8/21/76, 1930-2015 Tide: +8.6 ft
Actual Depth: 22-25 feet below water surface
Corrected Depth: 13-16 feet below MLLW

The subtidal area observed in the vicinity of Spring Point (Figure 17) was generally gently undulating cobble with scattered boulder patches and pockets of very silty shell debris and sand. Occasional boulders up to 6 feet high were observed. Shell debris was composed mainly of barnacle shell material. A light cover of silt covered all surfaces and was easily resuspended by light turbulence.

The biota was strongly dominated by suspension feeding organisms, particularly barnacles, bryozoans, hydroids, sponges and a brittlestar (Appendix C-8). Rock surfaces were extremely jagged and rough as a result of heavy encrustation of Balanus and bryozoans. The main barnacle was a medium sized, heavily ribbed Balanus rostratus alaskanus; all individuals were heavily encrustéd with tan, orange or brown bryozoans, mainly ?Pachyegis sp. and Parasmittina sp., which also encrusted a large portion of the rock surface and shells. Large heads of the tan frilly bryozoan Bidenkapia spitsbergensis and the red-orange thick branched Costazia ?procumbens were common and provided concealment for numerous other animals such as the shrimp Lebbeus prionotus, the brittlestar Ophiopholis aculeata, and the snails Buccinum glaciale and Margarites pupillus. Large coolonies of the fleshy bryozoans Flustrella gigantea and Alcyonidium ?pedunculatum were common, as well as large, thin, lobes of Carbasea carbasea. Common sponges were the orange, stalked, kidney-shaped Esperiopsis quatsinoensis, and the yellow encrusting Halichondria panicea and Mycale lingua. Several sertulariid hydroid species (Abietinaria variabilis, A. filicula, and Sertularia cupressoides) and Grammaria abietina extended above the substrate to filter the currents. The main filter feeding mollusc was the rock jingle Pododesmus macroschisma.

Numerous scavenger species were observed in the area. These included mainly juvenile pandalid shrimp and the large hermit crabs Pargurus ?tanneri, Elassochirus gilli, and P. beringanus.

Predators were common and included the snails Buccinum glaciale, Fusitriton oregonensis and Neptunea lyrata and the starfish Crossaster papposus and Leptasterias polaris var. acervata. Predatory behavior was also observed in the starfish Henricia sanguinolenta (Table 28).

Density and size data for several macroinvertebrates were presented in Table 29 and Appendix C-8a. Density data for the starfish are more realistic; the gastropods were less visible because of heavy encrustation and burrowing behavior.

Algal cover was quite light and strongly dominated by encrust-

Table 28. Feeding observations in subtidal area off Spring Point, Chinitna Bay, 8/21/76.

Predator	Prey	No. of Observations	Type of Observation
Henricia sanguinolenta	Mycale lingua	6	Direct
Leptasterias polaris acervata	Balanus rostratus	Several	Direct
	Musculus discors	1	Direct
	Mopalia sp.	1	Direct
Crossaster papposus	Tan encrusting bryozoan	2	Direct
	Abietinaria spp.	1	Direct

Table 29. Density of some macro-invertebrates in subtidal area in 10 x 1 m quadrats off Spring Point, Chinitna Bay, 8/21/76.

SPECIES	Quadrat 1	2	3	$\bar{x} \pm s$	No. per sq.m.
Crossaster papposus	1	0	1	0.67	0.07
Fusitriton oregonensis	0	1	0	0.33 ±	0.03
Henricia spp.	3	2	1	2.0 ±	0.20
Laptasterias polaris var. *acervata*	1	2	1	1.33 ±	0.13
Neptunea lyrata	3	2	0	1.67 ±	0.17
Strongylocentrotus drobachiensis	0	0	1	0.33 ±	0.33

ing forms (Table 30). The main fleshy algae were the brown *Desmarestia ligulata* and the reds *Callophyllis* sp., *Odonthalia kamschatica* and *Phycodrys* sp. The large brown *Laminaria groenlandica* was observed only on top of the large boulders (5-6 feet high). Only encrusting algae were widespread (Appendix C-8).

Several herbivores were observed but most were microherbivores which feed on periphyton or small filamentous forms. These included the chitons *Tonicella lineata*, *T. insignis* and the gumboot *Cryptochiton stelleri*. Sea urchins were uncommon.

Trophic dynamics were somewhat complex but heavily dominated by suspension feeders, which were competing strongly for space. Drift algal material and suspended organic debris were important food materials but local plant production is probably not directly important to the system. Light attenuation caused by turbidity, particularly from the resuspension of fines by tidal currents, probably is a very important cause for algal impoverishment. Judging from the abundance and size of fragile bryozoan colonies, abrasion is unimportant.

6.2.2.2 Chinitna Bay, Clam Cove Reef

Date: 8/22/76, 1430-1600 Tide: +11.7 feet

Actual Depth: 16'-22' below water surface

Corrected Depth: 4 to 10 feet below MLLW

Location: On Clam Cove Reef, on the N. side of Chinitna Bay, about 3 mi. W. of Spring Point

The subtidal area observed on this reef (Figure 17) was moderately smooth bedrock with scattered rounded boulders and patches of shell debris. There was little surface relief. Little silt deposition was observed.

Table 30. Relative cover (%) of macrophytes in 1/4 m^2 quadrats from off Spring Point, Chinitna Bay, 8/21/76

	1	2	3	4	5	6	7	8	9	10	$\bar{x} \pm sd$
Callophyllis sp.	0	3	10	5	0	0	3	0	0	0	2.1 ± 3.3
Desmarestia ligulata	0	5	0	0	0	15	5	5	0	2	3.2 ± 4.7
Encrusting coralline	60	55	40	50	60	35	30	50	30	30	44.0 ± 12.4
Hildenbrandia sp.	5	2	2	2	2	2	3	10	3	0	3.1 ± 2.7
Laminaria groenlandica	0	0	0	0	0	0	0	15	0	0	1.5 ± 4.7
Odonthalia kamschatica	0	5	2	5	5	3	0	0	0	0	2.0 ± 2.3
? *Opuntiella* sp.	2	0	0	0	0	0	14	5	0	0	2.2 ± 4.8
Phycodrys sp.	0	0	5	5	10	0	0	0	0	0	2.0 ± 3.5
Rhodophyta, fleshy	0	0	2	0	0	0	0	0	0	0	0.2 ± 0.6

Depth 22-35 ft (6.7 - 7.6 m)

The biota was visually dominated by kep species, particularly Alaria ?marginata and Laminaria groenlandica. The latter was most abundant and covered a greater area (Table 31), but Alaria was important. Their density and relative cover were spatially variable as indicated in Appendices C-9 through C-9c. Of the other fleshy algae observed (Appendices C-9b and C-9c), only Odonthalia kamschatica was common. Several encrusting species formed a pavement on the rock. Encrusting coralline algae were the most important species, but Ralfsia was also common.

The most abundant herbivores forms were microherbivores. The most abundant species was the lined chiton (Tonicella lineata). Limpets and Margarites pupillus were common (Appendix C-9c). These species may account for the poor development of the algal understory and the well developed pavement of encrusting algae. Sea urchins wre not observed on this reef.

The suspension feeding assemblage was not well developed. The most important group was a mat-forming sabellid polychaete (Potamilla sp.) (Table 31). Other common taxa were hydroids (Abietinaria inconstans and Eudredrium vaginatum) and a snail (Trichotropis insignis).

The predator/scavenger assemblage also was generally poorly developed. Small hermit crabs were common (Table 31), but most other taxa were uncommon (Appendices C-9 and C-9c).

Although a wide variety of organisms was observed on this reef, only seaweeds and suspension feeders were common. Considering the importance of seaweed and the absence of macroherbivores, it appears that the reef is generally an export system. The amount of habitat of this type in Chinitna Bay is limited, however. Competition for space by

Table 31. Coverage and density of important organisms on Clam Cove Reef, Chinitna Bay, 8/22/76

SPECIES	Percent Cover	Density (No./m^2)
Alaria marginata [a]	30.6 ± 21.1%	3.4
Encrusting coralline algae [b]	50.3 ± 16.6%	-
Laminaria groenlandica [a]	52.8 ± 26.5%	18.2
Odonthalia kamschatica [b]	5.6 ± 6.7%	-
Ralfsia pacifica [b]	6.4 ± 6.3%	-
Abietinaria spp. [c]	3.0 ± 2.4%	-
Acmaeidae, unid	-	3.0
Eudendrium vaginatum	1.5 ± 2.4%	-
Pagurus sp.	-	9.0
Potamilla sp.	22.5 ± 24.0%	-
Tinicella lineata	-	48.0
Trichotrophis insignis	-	10.0

Depth: 16-22 ft (4.9-6.7m)

a Based on 16-1/4 m^2 quadrats and 3-5 m^2 quadrats

b Based on 16-1/4 m^2 quadrats

c Faunal species based on 4-1/4 m^2 quadrats plants or animals appears weak. The nature and location of the sedentary species suggest that ice scour may be an important factor on this reef, limiting development of fragile organisms such as bryozoans. However, the abundance of mature specimens of perennial seaweeds weaken this conclusion.

7.0 QUALITATIVE INFAUNAL SAMPLING

Small replicate core samples were collected at each of the eight sampling sites dominated by sand. That included five sites on the east side of the Inlet and three sites on the west. Nearly all the samples were collected from several levels below MLLW. The data for each station are listed in Appendices D-1 through D-8.

7.1 Numerical Comparisons

The infauna in the samples was dominated by polychaetes and crustaceans; the only other organisms were a few species of bivalves. In all, 31 species were collected (Table 32).

The number of species collected at a station ranged from three at Polly Creek to nine at the base of Homer Spit, on the west side. The number of species per station did not differ significantly between the two sides of the inlet. However, the number of species per station may decrease from south to north on both sides of the inlet (Table 32).

The number of specimens collected at a station ranged from seven at Polly Creek to 87 at Clam Gulch. The stations on the east side of the inlet generally produced more specimens.

The number of specimens per station increased dramatically from south to north on the east side of the inlet, but the pattern was essentially reversed on the west side. By correcting for differences in the number of cores collected per site, and looking at the average number of specimens per core, those patterns are accentuated.

This same pattern is apparent for the number of specimens per species.

Table 32 . Number of species and individuals in infaunal core samples at stations in Lower Cook Inlet

Location	Number of Species	Number of Individuals
East side of Lower Cook Inlet		
Base of Homer Spit	9	17
Seafair Beach	7	16
Whiskey Gulch	5	40
Deep Creek	5	44
Clam Gulch	6	87
West Side of Lower Cook Inlet		
Amakdedori	7	25
Chinitna Bay clam beach	7	25
Polly Creek	3	7

Total number of infaunal species 31

Sufficient data have not been collected to determine the significance of these patterns or to establish their meaning, if significant.

The number of animals per sq. m. ranged from about 140 at Polly Creek to about 1,100 at Clam Gulch. The taxon exhibiting the highest density was *Eohaustorius* spp., with about 1,000 per sq. m. at Clam Gulch. *Paraphoxus obtusidens major* had the highest density for an identifiably single species; its density was about 140 per sq. m. at Whiskey Gulch.

7.2 Faunal Comparisons

The infaunal species comprised 14 polychaete, 10 crustacean and 3 bivalve species, but, in terms of specimens, crustaceans were more numerous, largely because of the gammarid *Eohaustorius* spp. Of the 27 taxa, 13 were found only on the east side, five were found on both sides, and nine were found only on the west side. The five common taxa were *Eohaustorius* spp., another gammarid *Paraphoxus obtusidens major*, and three polychaetes, *Nephtys* nr *caeca*, *N.* nr. *parva* and *Eteone* nr. *longa*, all of which were probably ubiquitous. None of the species that were found on only one side were found with sufficient regularity to be considered characteristic of one side. In fact, although the respective assemblages appear quite dissimilar, that conclusion is unwarranted because the frequency of occurrence of the "nonjoint" species is so low. It is quite possible that additional sampling would detect most of these species on both sides of the inlet.

A list of "important" taxa is compiled in Table 33. To qualify for this list, a taxa had to among the three most numerous organisms at one station, and must also be represented by two or more specimens. Eighteen taxa met these qualifications. A major function of this table

Table 33. Densities[1] of selected infaunal species from sandy beaches in Lower Cook Inlet, May, June and July 1976.

Location / Approx. Elevation (ft)	Base of Homer Spit 0 to -1	Base of Homer Spit -4	Seafair Beach 0 to -1	Seafair Beach -4	Whiskey Gulch 5/ 0	Whiskey Gulch 0 to -1	Whiskey Gulch -1	Whiskey Gulch -2	Deep Creek +2 and -2	Deep Creek -3	Clam Gulch -2	Clam Gulch -4 4/	Amakdedori +1	Amakdedori -2	Amakdedori -3	Chinitna Clam Beach -3 4/	Chinitna Clam Beach -4	Polly Creek -1	Polly Creek -3
ANNELIDA-Polychaeta																			
Eteone nr. longa	2/	-	2/		-	-	-	-	3/	0.17±0.41	-	-	3/	-	-	0.17±0.41	0.17±0.39	2/	-
Magelona sacculata		-		0.50±0.84	-	-	-	-		-	-	-		-	-	-	-	-	-
Scoloplos armiger		0.33±0.52		-	-	-	-	-		0.33±0.52	-	-		-	-	-	-	-	-
Scolelepis sp.		-		-	-	-	0.50	-		-	-	-		-	-	-	-	-	-
Spionidae #1 C		-		-	-	-	-	-		-	-	-		0.83±0.75	-	-	-	-	-
Spio filicornis		-		-	-	-	-	-		0.33±0.52	-	0.17±0.39		0.33±0.52	1.33±1.75	-	-	-	-
Spiophanes bombyx		0.33±0.82		0.33±0.82	-	-	-	-		0.33±0.52	-	0.5± 0.9		-	-	-	-	-	-
Paraonidae, unid																			
AMTHROPODA-Crustacea																			
Anisogammarus pugettensis		-		-	-	-	-	-		-	-	-		-	0.33±0.82	-	-	-	-
Anonyx sp. A		-		-	-	0.33	-	-		-	-	-		-	-	-	-	-	-
Archaeomysis grebnitzkii		-		-	-	-	-	-		-	-	-		-	-	-	-	-	0.50±0.84
Cumacea, unid		0.67±0.82		-	-	-	-	0.17±0.41		-	-	-		-	-	-	-	-	-
Eohaustorius spp.		0.17±0.41		0.33±0.82	1.33	0.33	-	1.50		6.00±4.86	3.83±5.31	4.33±3.96		-	-	0.92±2.31	0.50±0.55	-	0.67±1.21
Hippomedon sp. A		0.67±0.52		1.0±1.26	-	-	-	-		-	-	-		-	-	-	-	-	-
Paraphoxus obtusidens		0.17±0.41		0.17±0.41	-	-	-	-		-	-	-		-	-	-	-	-	-
P. o. major		-		0.17±0.41	1.33	0.33	-	0.83 -		0.17±0.41	-	-		-	-	0.17±0.41	-	-	-
?Neomysis sp.		-		-	-	-	-	-		-	-	-		-	-	0.17±0.58	-	-	-
MOLLUSCA-Pelecypoda																			
Siliqua patula (juvenile)		-		-	-	-	-	-		-	-	-		0.17±0.41	0.50±1.22	-	-	-	-

1/ Average number/44 sq. cm.
2/ No animals collected in 6 cores
3/ Two sets of 6 cores taken
4/ Twelve cores taken
5/ Samples inadvertently pooled; s not calculable

is to summarize Appendices D-1 through D-8. It also clearly demonstrates that both the number of species and specimens increase sharply with increasing distance below MLLW.

8.0 DISCUSSION

Our studies support the frequent contention that Lower Cook Inlet is a productive and complex body of water. In fact, productivity and complexity exceeded our expectations. The assemblages include clean exposed open coast systems that are dominated by giant laminarian kelps, quiet estuaries and lagoons, exposed sandy beaches, mudflats and silty, physically inhospitable benches. But in almost all instances, the assemblages exhibited considerable primary (plant) or secondary (animal) productivity; plant productivity varied enormously among the different sites.

Among the major points to be addressed in this discussion are: 1) notable species discoveries and patterns, 2) descriptions of the basic habitat types and biotic assemblages, and 3) trophic structure, energy production and utilization patterns.

8.1 Dominant Biological Assemblages

The basic types of biological assemblages encountered during this survey corresponded rather closely with three major substrate types, namely mud, sand and rock. As with the substrates, mixing of assemblages and variations in composition were the rule; however, each type of assemblage was characterized by the presence or absence of particular groups of organisms.

8.1.1 Mud Flat Assemblages

The mud flat assemblage in Lower Cook Inlet is a moderately variable intertidal assemblage located in bays and estuaries; it is generally representative of very protected situations. The assemblage is mainly typified by suspension feeders such as soft-shell clams (Mya spp.), and deposit feeders like the pink clam Macoma balthica and a large burrowing polychaete worm Nephtys caeca. The spoonworm (Echiurus echiurus alaskanus), a suspension feeder, is also a frequent component. Most of the organic debris utilized by this assemblage is imported from other habitats, and plant productivity is usually low.

Eelgrass beds are generally found in similar environments, but fairly clear water is required. The faunal assemblage may be quite different, particularly with respect to the clams. In Koyuktolik Lagoon, the principal clams are butter clams (Saxidomus giganteus), littlenecks (Protothaca staminea) and gapers (Tresus capax), but in Kamishak Bay, the soft-shell clams were characteristic of mudflat assemblages.

8.1.2 Sand Beach Assemblage

The faunal assemblages found on sandy beaches are simple and revolve around the clam worm Nepthys nr. caeca, the polychaetes Scolelepis sp. and Spio filicornis, and the redneck clam Spisula polynyma, razor clams (Siliqua patula and S. alta) and a large tellinid (Tellina lutea). These species vary in abundance and distribution in response to silt content of the substrate, currents, salinity and other physical and biological parameters.

The faunal assemblages on a sand beach are composed almost entirely of suspension and deposit feeders, and are heavily dependent upon imported organic debris for food.

8.1.3 Rocky Intertidal Assemblages

The biological assemblages encountered on rocky substrates exhibit several similar characteristics, regardless of whether they grow on bedrock or in a boulder field. The most basic components of these assemblages appear to be barnacles and mussels, both of which are suspension feeders, and a whelk such as *Nucella*, which preys on the suspension feeders. This type of assemblage was observed on rocks at Deep Creek and Clam Gulch. In more favorable locations, seaweeds and herbivores are added to the assemblage. Increasing complexity of the algal and herbivore assemblages accompanies increased suitability of the environment. Other things being equal, by increasing the quantity and the supply of organic debris, the suspension feeding assemblage usually becomes more diversified. Any such increase in diversity will generally be accompanied by a similar increase in the diversity of the predator assemblage (Paine, 1966).

Rocky habitat is common on the west side of the inlet and dominant in the southeastern quadrant. However, the level of complexity of the assemblages observed in these two areas differs considerably. In the southeastern region, the assemblages are extremely complex and the lush vegetation is strongly dominated by laminarian seaweeds. In contrast, similar assemblages, located primarily at the mouth of some bays, are an exception on the western shoreline where most rocky habitats are dominated by pioneer species. Extremely high densities of newly settled barnacles coat the rocks in the mid-intertidal and a thin cover of green and red algae grow on the lower intertidal rocks.

The principal factors causing the lower diversity and plant productivity on the western shoreline are probably high turbidity and sedimentation, low air temperatures and ice abrasion. The effects of sedimentation are obvious; it is common to see a rock with a thin veneer of silt pockmarked by small craters that indicate the location of barnacles attempting to feed. The effects of ice abrasion are somewhat more subtle when the ice has disappeared. Clues are seen in the presence of adult barnacles surviving only in small depressions on smooth, rounded bedrock that is covered with newly settled barnacles. The only mature organisms observed are located in protected locations such as a depression, a crevice or under one of the rather uncommon boulders.

Of the physical factors noted, ice abrasion and low air temperature probably affect the most area over the long term. However, the occurrence is extremely unpredictable. Since 1970, for instance, maximal ice cover in Lower Cook Inlet has ranged from just south of Kalgin Island in the winter of 1973-74, to a line extending from Cape Douglas to Anchor Point, in 1970-71 (NOAA 1972, MS).

8.1.4 Rocky Subtidal Assemblages

Rocky subtidal habitats have been examined at numerous locations on the east side of Lower Cook Inlet, in Kennedy Entrance and outer Kachemak Bay as far north as Anchor Point. The only subtidal observations on the west side have been in and around Chinitna and Iniskin Bays. However, even based on these few observations, it appears that the biotic assemblages below a depth of about 3 m are distinctly different on the two sides of the inlet. On such substrate, habitats on the east side are dominated by kelps to a depth of at least 20 m (Dames & Moore, 1976a), whereas on the west side they are dominated by barnacles, encrusting bryozoans and sponges (see also Dames & Moore, 1976).

On the east side, the areas examined can be arbitrarily divided into two general depth zones, namely, -3 to -12 m and -12 to -20 m, based on visual appearance in the summer. The visually dominant species in the upper zone in summer are the seaweeds Alaria fistulosa and Nereocystis luetkeana, and in the winter, Laminaria groenlandica and Agarum cribrosum. Seaweed standing crop is quite high. The latter two species are visually dominant in the lower zone year-round. Algal biomass is reduced in the lower zone and declines with increasing depth. The vertical boundaries on these zones vary a fair amount locally, and the geographic distribution of A. fistulosa and Nereocystis are quite variable annually, but general patterns are fairly reliable.

The faunal assemblages on the east side vary much more horizontally than vertically over the depth range examined. Apparently, however, barnacles, encrusting bryozoans and sponges become more important with increasing depth on the east side of the inlet. A number of the important species are listed in Tables 19, 20 and 22. The major herbivores are sea urchins (Strongylocentrotus spp.) and chitons (mainly Tonicella spp. Suspension feeders form the greatest faunal component in terms of numbers, biomass and relative coverage of the substrate. Major taxa include sponges (e.g., Halichondria panicea, Mycale ?lingua and ?Esperiopsis laxa), polychaete worms (e.g., Potamilla spp. and Owenia collaris), pelecypods (e.g., Modiolus modiolus, Saxidomus giganteus, Serripes groenlandicus and Macoma spp.), bryozoans (e.g., Flustrella gigantea and Microporina borealis), hydroids (Abietinaria spp.), the brittlestar Ophiopholis aculeata, and several tunicate species (e.g., Ritterella rubra). Competition for space among macrophytes and suspension feeders is generally strong, and very intense in areas of high water turbulence.

Predator assemblages are quite varied on the east side of the inlet, and generally specimens are robust and numerous. Starfish are very important predators; at least sixteen species have been observed in Kachemak Bay. The most important species included (Evasterias troschelii, Dermasterias imbricata, Pycnopodia helianthoides and Crossaster papposus. Important demersal fish included several species each of greenling, cottid and flatfish. Predation pressure by fish appears to be highly seasonal; they move into the shallower water mainly during late spring and remain through the summer.

Two large snail species, Fusitriton oregonensis and Neptunea lyrata, are abundant throughout a wide area in the rocky subtidal areas. Both probably are facultative scavengers.

Based on the small number of observations available from the west side of the inlet, it appears again that two depth zones can be distinguished based on visual dominance patterns. However, the zones are distinctly different from those on the east side. Seaweeds generally become unimportant below a depth of-3 m (Table 30, Appendix C-6). Between 0 and -3 m, the dominant kelps were Laminaria groenlandica and Alaria ?marginata (Tables 23, 24 and 31). Bottom coverage by encrusting coralline algae was considerable between -3 and -6 m (Tables 24, 30 and 31) but became sparse or absent below -6 m (Appendix C-6; Dames & Moore, 1976). Kelp species conspicuously absent included Nereocystis, Alaria fistulosa and Agarum cribrosum.

A fairly distinct difference in faunal composition was apparent between these depth levels. Above -3 m, most of the individuals were cryptic and juvenile specimens prevailed. Furthermore, species diversity was rather low (Tables 24 and 31). Encrusting assemblages were poorly developed. Below -3 m, encrusting species formed a well developed epifaunal mat, in which dominant taxa included barnacles (Balanus rostratus alaskensis), sponges (Mycale ?lingua and Halichondria panicea) and bryozoans (Bidenkapia spitsbergensis, Costazia spp., Parasmittina sp., and Rhamphostomella spp.). A very similar assemblage was observed in deeper water east of Chinitna Bay in a previous study (Dames & Moore, 1976).

Sea urchins were the primary herbivore and quite abundant below -3 m. In view of the paucity of attached algal material, however, it is probable that they are primarily acting as scavengers.

The predator assemblage was not diverse, comprising mainly starfish, snails and fish. The main fish observed was the white-spotted greenling. The major starfish were Leptasterias polaris var. acervata and Crossaster papposus, the former being by far the most important. The main snails were a cryptic species, Buccinum glaciale, which was abundant, and Fusitriton oregonensis.

The upper subtidal levels examined on the west side did not appear to support diverse assemblages or contain many mature specimens of long-lived species. Juveniles and annuals predominated. The cause of this pattern is unknown but may be related to ice abrasion in the winter or water turbulence. It seems likely that the former is most influential.

Surprisingly, the resemblance between the rocky subtidal assemblage on the west side of the inlet and that off Point Barrow (MacGinitie, 1955) is fairly strong. Generally, barnacles, bryozoans and sponges are dominant encrusters. Furthermore, many of the species are common to both areas. This is particularly conspicuous for the bryozoans, where at least 20 of the 30 important species discussed by MacGinitie were also important in western Lower Cook Inlet. Other groups with notable similarity included polychaetes, echinoderms, pelecypods and some smaller phyla.

8.2 Notable Species Distribution Records

Because of existing or potential commercial importance, or previously published reports, the observed distribution or abundance of some species warrant discussion. The most important of these are soft-shell clams (*Mya* spp.), king crab (*Prvalithodes camtschatica*) and eelgrass (*Zostera marina*). The occurrence of several other species constitutes sizable range extensions. Notable among these are some bryozoans (e.g., *Bidenkapia spitsbergensis* and *Alcyonidium enteromorpha*), (Osburn, 1950, 1953).

8.2.1 Soft-Shell Clams

The eastern soft-shell clam (*Mya arenaria*) forms the basis for a commercial fishery along the eastern seaboard of North America (Orth, et al, 1975). Based on the abundance of *Mya* spp. on the west side of Lower Cook Inlet, and the large amount of habitat available, it would appear that the soft-shell clam is a potential commercial resource here. The genus *Mya* is represented in Alaska by *M. arenaria*, *M. elegans*, *M. priapus* and *M. truncata*. All four species have been collected in Lower Cook Inlet (Rae Baxter, ADF&G, personal communication). All live in fairly muddy substrates. *Mya arenaria*, *M. priapus* and *M. truncata* are among the most widespread organisms on the west side of the inlet and are strong numerical and biomass dominants. *Mya* spp. were conspicuous components of the faunas in all habitats examined except clean sandy areas. In addition to their potential commercial importance, the species undoubtedly are important in several food webs.

8.2.2 King Crab

The king crab is a species of considerable commercial importance and a substantial effort is being expended to unravel the life history and ecology of the species. An important facet of this effort has been attempting to locate king crab nursery areas. We discovered juvenile king crabs in the lower intertidal zone at the mouth of Iniskin Bay, where they were common under small boulders (up to six were commonly observed under one rock). Farther into the bay, on a similar but siltier rock bench, they were not found under rocks. Although not found intertidally at Chinitna, we observed juvenile king crab in a subtidal field off Spring Point in January, 1976.

8.2.3 Eelgrass

McRoy (1972)reported on a variety of aspects concerning the physiology and ecology of eelgrass. He provided a general picture of the importance of *Zostera* to both marine and terrestrial ecosystems. Distribution records indicated that Kachemak Bay was the only location on the southern Kenai Peninsula and in Lower Cook Inlet where *Zostera* had been recorded.

As a result of this and other studies, we have ascertained that eelgrass is rather widely distributed in this area. Its presence has been documented in Port Dick, Koyuktolik Bay (Dames & Moore, 1977), Seldovia, Jakolof and Kasitsna Bays (Rae Baxter, ADF&G, personal communication), on the southern Kenai Peninsula at Mud Bay, near Homer, and at Iniskin Bay, Bruin Bay and near the mouth of the Douglas River in Kamishak Bay on the west side of the inlet.

The largest beds observed so far are at Koyuktolik Bay and Bruin Bay; the approximate area of the bed in Koyuktolik Lagoon is 1,500,000 sq. m. and the bed at Bruin Bay as nearly half that size (Dames & Moore, 1977).

Although _Zostera_ is a perennial, the turions (leaf bundles) at Mud Bay, Iniskin Bay, Bruin Bay and near the Douglas River, appear to be acting like annuals, i.e., the bed may be completely stripped of leaves nearly every year. This is not the case for the populations at Koyuktolik or Port Dick, however, except in an isolated location. We hypothesize that removal occurs during the winter, after the blades die from exposure or freeze to the bottom of ice blocks stranded during low tides.

Eelgrass beds are known to be highly productive and contribute plant material to both marine and terrestrial systems. However, data for this area are insufficient to determine the importance of these beds relative to other producer assemblages and available plant materials in Lower Cook Inlet.

8.3 Food Webs in Lower Cook Inlet

Numerous feeding observations were made during this study and are presented in Tables 27, 28 and 34 and Appendices C-1g and C-4h. These data have been further summarized in Figures 19, 21, 22 and 23, and Table 35. Even though the figures are necessarily imcomplete and simplified, it is obvious that the trophic structure in Lower Cook Inlet is fairly complex. Five major gaps in the data relate to the effects of decomposers, fish, birds, crabs and the small predators such as snails and worms. Additionally, the data bases for the west side of the inlet and sand habitats are scanty.

Nevertheless, a few patterns are suggested by the available data. Sea urchins appear to be the only important macroherbivore in the systems examined. For the most part, macrophyte materials are destined to become drift as a consequence of blade erosion induced by wave action or currents, and are utilized mainly by the decomposer, deposit and suspension feeder assemblages. The distinction between these groups is rather vague. However, as working definitions, let us assume that the decomposers include mainly bacteria and fungi and suspension feeders and deposit feeders include invertebrates that feed on either suspended or deposited organic debris, respectively, and gain nutrition mostly from the decomposers living thereon. Organic debris acts mainly as a culture medium for decomposers and is recycled. Some suspension feeders also gain nutrition directly from phytoplankton.

A very large proportion of the faunal assemblages in the intertidal, nearshore and offshore assemblages is composed of detritus feeders, leading to the conclusion that these are mainly detritus-based assemblages. The suggested food web for mudflats (Figure 23) appears fairly standard throughout the areas examined in Lower Cook Inlet. Suspension feeders appeared to be very important, but deposit feeders were common. Local variation in consumer species is rather minimal and the major differences relate to relative proportions of component species.

This study produced no hard feeding data for trophic structure in intertidal or shallow sandy habitats. However, some basic pathways can be postulated (Figure 24). Deposit feeders appeared to be important. Again, these systems are detritus-based, and fairly uniform throughout Lower Cook Inlet.

On both mud and sand habitats, birds and fish are apparently very important predators (Figure 23 and 24). However, the major effects of both groups are markedly seasonal, occurring mainly from about April through late September. Effects from shorebirds and many ducks are even more periodic; extreme local pressure is exerted in intertidal and shallow subtidal areas during the very short periods of spring and fall

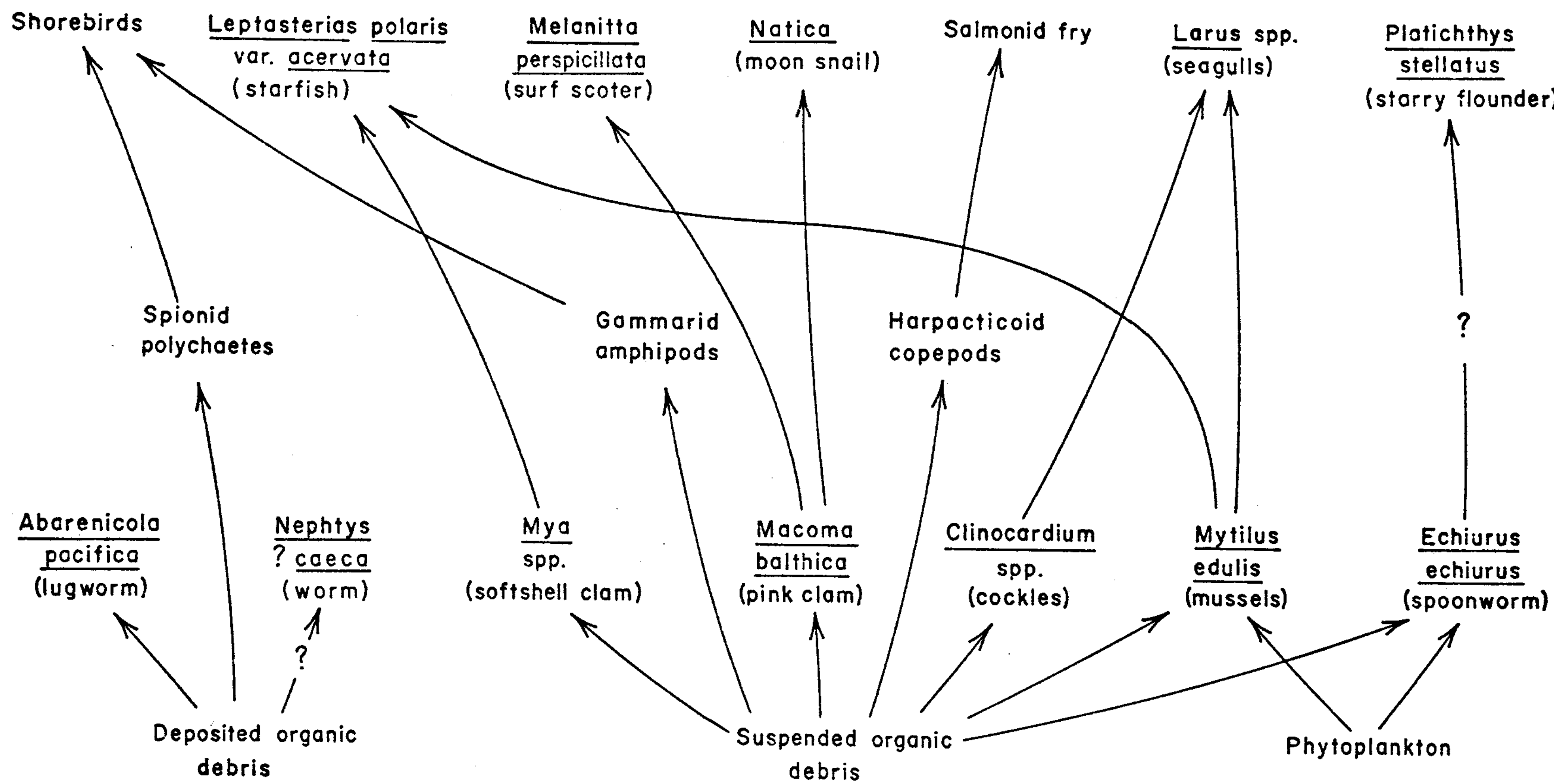


FIGURE 23

Food web for the characteristic faunal assemblage on mudflats in Lower Cook Inlet

Table 34. Summary of miscellaneous feeding data from intertidal observations, Lower Cook Inlet, Summer 1976.

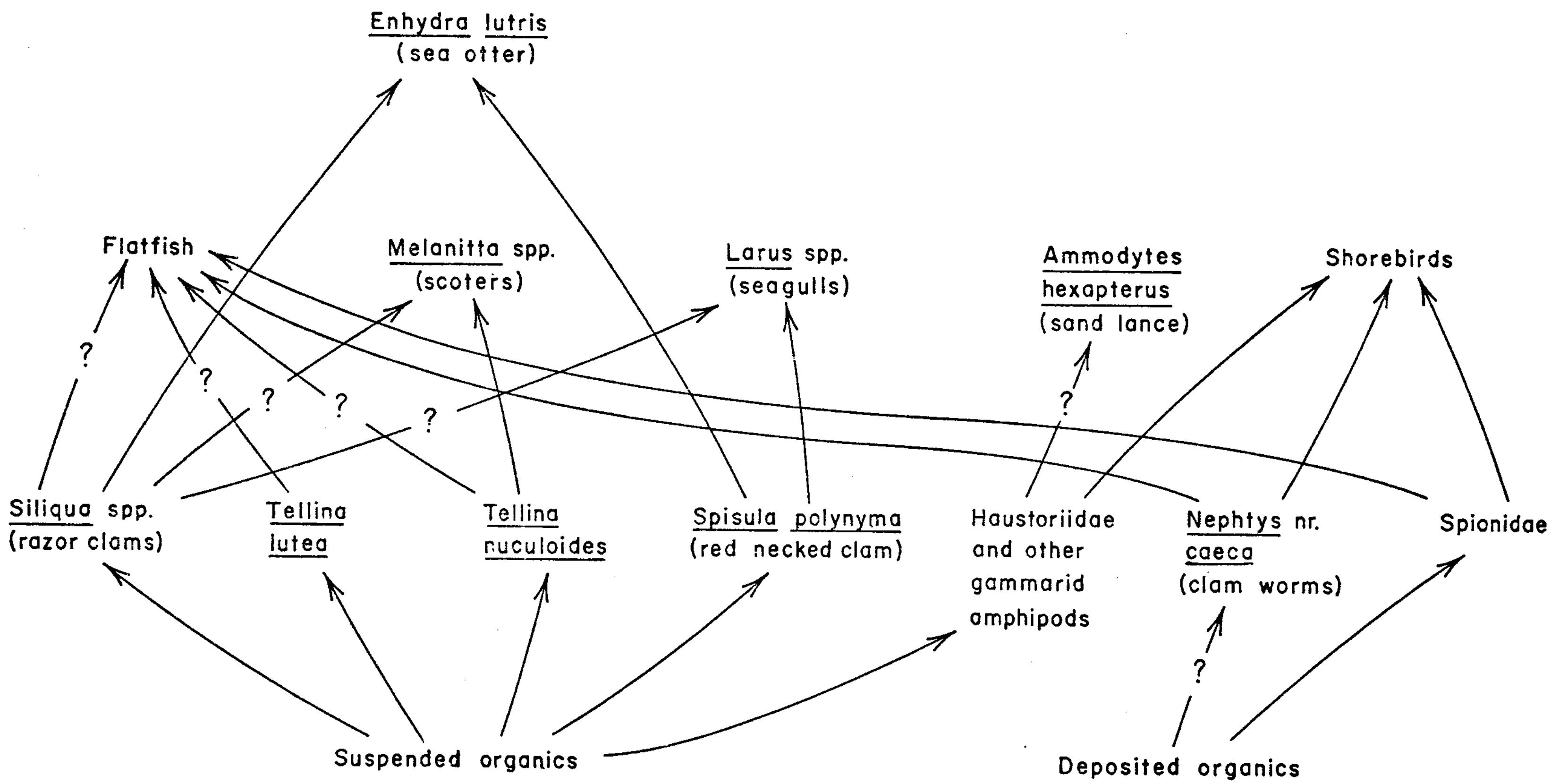
Location/Predator	Date	Prey	Number	Type of Observation
Mud Bay, Homer	7/13/76			
Melanitta perspicillata (surf scoter)		*Macoma balthica*	Numerous	Indirect
Larus sp. (sea gulls)		*Mytilus edulis*	Numerous	Indirect
		Clinocardium nuttalli	Numerous	Indirect
Seafair Beach	5/13/76			
Nucella emarginata		*Balanus glandula*	Numerous	Direct
		Mytilus edulis	Several	Direct
1 mi. W. of Seafair Beach	5/16/76			
Cribrinopsis similis		*Strongylocentrotus drobachiensis*	1	Direct
Whiskey Gulch	5/12/76			
Leptasterias hexactis		*Balanus glandula*	Several	Direct
		Gammaridea, unid.	1	Direct
Byers Site, Chinitna Bay	6/09/76			
Melanitta perspicillata (surf scoter)		*Macoma balthica*	Numerous	Indirect
Spring Point, Chinitna Bay	6/09/76			
Cribrinopsis similis		*Telmessus cheiragonus*	1	Direct
Nucella emarginata		*Balanus* spp	Numerous	Direct
Rocky Point, Iniskin Bay	6/12/76			
Leptasterias polaris acervata		*Mya truncata*	Several	Direct
		Macoma ? obliqua	Several	Direct
		Mytilus edulis	1	Direct
Low rock bench off Keystone Creek, Iniskin Bay	6/13/76			
L. p. acervata		*Macoma balthica*	1	Direct
		Mya ? arenaria	1	Direct
Tealia crassicornis		*Balanus glandula*	1	Direct
Brownie Cove, Bruin Bay	6/14/76			
Natica sp.		*Macoma balthica*	Numerous	Indirect
Melanitta perspicillata (surf scoter)		*M. balthica*	Numerous	Indirect
Douglas River, Kamishak Bay	6/15/76			
Larus sp. (sea gulls)		*Balanus* sp.	Several	Indirect; egesta
		Brachyura, unid	Several	Indirect; egesta
		Clinocardium sp.	Several	Indirect
Melanitta perspicillata (surf scoter)		*Macoma balthica*	Numerous	Indirect
Nucella emarginata		*Balanus glandula*	Several	Direct

Table 35. Summary of feeding observations observed during reconnaissance survey, summer 1976.

Predator	Prey	Number of Observations
Aeolidida, unid	Hybocodon prolifer	Several
Cribrinopsis similis	Strongylocentrotus spp.	1
	Telmessus cheiragonus	1
	Alcyonidium ? pedunculatum	1
Crossaster papposus	Flustrella gigantea	Several
	Abietinaria spp.	Several
	Sertulariidae, unid	Several
	Tan encrusting bryozoan	2
	Microporina borealis	Several
	Tonicella spp.	Several
Dendronotus sp.	Hydroida, unid.	
Dermasterias imbricata	Metridium senile	Numerous
	Strongylocentrotus spp.	Numerous
Enhydra lutris	Balanus nubilus	Numerous
	Strongylocentrotus spp.	Numerous
	Modiolus modiolus	Numerous
	Saxidomus giganteus	Numerous
	Fusitriton oregonensis	Numerous
	Neptunea lyrata	Numerous
Evasterias troschelii	Modiolus modiolus	2
	Saxidomus giganteus	1
Fusitriton oregonensis	Modiolus modiolus	Several
Henricia sanguinolenta	Mycale lingua	Numerous
Larus spp.	Balanus spp.	Several
	Clinocardium nuttallii	Numerous
	Enhydra lutris	Numerous
	Mytilus edulis	Numerous
	Brachyura, unid	Several
Leptasterias hexactis	Balanus glandula	Several
	Gammaridea, unid	1

Table 35. (Cont.)

Predator	Prey	Number of Observations
Leptasterias polaris var. acervata	Balanus rostratus alaskanus	Numerous
	Clinocardium californiense	1
	Macoma ? obliqua	Several
	Modiolus modiolus	Numerous
	Mopalia sp.	1
	Musculus discors	
	Mya ? arenaria	1
	Mya truncata	Several
	Mytilus edulis	1
	Pectinaria granulata	1
	Protothaca staminea	1
	Saxidomus gigantea	Several
Melanitta perspicillata	Macoma balthica	Very numerous
Natica sp.	Macoma balthica	Numerous
	Macoma sp.	Numerous
Neptunea lyrata	Modiolus modiolus	Several
	Saxidomus giganteus	Several
Nucella emarginata	Balanus glandula	Numerous
	B. rostratus alaskanus	Numerous
	Mytilus edulis	Several
Orthasterias koehleri	Balanus nubilus	2
Paguridae, unid.	egg masses of Fusitriton and Neptunea	Numerous
Pteraster tesselatus	Microporina borealis	
	Flustrella gigantea	Several
	Abietinaria sp.	1
	Sertulariidae, unid	Several
	Mycale sp.	1
Pycnopodia helianthoides	Modiolus modiolus	Numerous
	Saxidomus giganteus	Numerous
	Strongylocentrotus spp.	Numerous
Scyra acutifrons	Saxidomus giganteas	1
Solaster dawsoni	Cucumaria miniata	2
Strongylocentrotus drobachiensis	foliose reds	Numerous
	Agarum cribrosum	Numerous
	Alaria spp.	Numerous
	Laminaria spp.	Numerous
	Nereocystis luetkeana	Numerous
Tealia crassicornis	Balanus glandula	1



Postulated food web for sand beach assemblages in Lower Cook Inlet

FIGURE 24

migrations. Most of the larger fish species observed in the shallow habitats spend only spring and summer there, and move into deeper water during fall and winter. In spite of the seasonality of these predators, the apparent intensity of their activities when present would indicate that their impact on their prey species is considerable.

Such simplistic food webs cannot be prepared for rocky substrates. In most current swept areas, suspension feeders predominate. Local variations in species composition, even of the dominant species, are large and necessitate a more site-specific approach (Figures 19, 21 and 22). The systems are quite complex.

8.4 Plant Materials as Food Sources

Plant materials are the basic food source for all major food webs. Three major sources of plant material appear to support the biological assemblages in Lower Cook Inlet, namely, (1) phytoplankton, (2) macrophytes, and (3) organic debris of terrestrial origin. As an initial, rough estimate these materials may be equally important quantitatively. However, importance varies considerably seasonally.

Major phytoplankton production occurs in Kackemak Bay and in Kennedy Entrance; lower levels of phytoplankton also occur in Kamishak Bay and elsewhere in Lower Cook Inlet (Jerry Larrance, PMEL, personal communication). Production is apparently quite low from about October through March, and probably peaks in May or June.

The shores of Kachemak Bay and Kennedy Entrance are the site of maximal macrophyte production; appreciable production extends past a depth of 20 m. Levels of macrophyte production are probably rather low on the west side of Lower Cook Inlet, and negligible north of a line from Whiskey Gulch to Chinitna Bay. Algal production generally appears inconsequential below a depth of 3 m on the west side of the inlet.

Temporal patterns in macrophyte production are more complex than in phytoplankton. Two major kelp forms (Alaria spp. and Nereocystis luetkeana) are highly productive in spring and summer and virtually disappear during fall and winter (Dames & Moore, 1976a). In the southeast quadrant of the inlet, two species in this group (Alaria fistulosa and Nereocystis) form dense, extensive surface canopies in late summer. These "beds" contribute massive quantities of algal debris to detritus-based food webs during the early fall storms. Extrapolating from studies at a lower latitude, such detrital materials may remain useful to detritus feeders for at least three months (Zobell, 1959). Two other major kelp species (Agarum cribrosum and Laminaria groenlandica) probably grow most rapidly during late winter and early spring (Mann, 1972; personal observation), and also contribute considerable detrital material to detritus-based food webs. However, their contribution is probably more evenly distributed in time and continues during winter, when phytoplankton stocks are at a minimum.

The major sources of organic debris of terrestrial origin are major river systems entering Cook Inlet. These materials enter largely as detritus with freshwater runoff and probably periods of peak contribution are after fall rainstorms and during spring "break-up". Besides the major rivers (the Susitna and Knik Rivers), the numerous small watersheds on the west side of the inlet are probably of great local importance.

8.5 Patterns of Energy Production and Utilization

The intertidal assemblages in Lower Cook Inlet can be roughly divided into two energy regimes, namely, areas of net energy import and net energy export. Areas dominated by suspension or deposit feeders, such as sand and mud habitats, are essentially energy import systems; import of organic material is necessary to support the system. It is important to realize that, in addition to the sandy and muddy intertidal and shallow subtidal assemblages described in this report, all benthic assemblages located below the euphotic zone (and therefore a very large proportion of Cook Inlet) are import systems. Most crab and shrimp fisheries operate in such areas. Biotic assemblages in which plants produce more organic materials than are required by their faunas are essentially energy export systems. Rock habitats and eelgrass beds usually include macrophytes, suspension feeders, deposit feeders and herbivores, as well as predators and scavengers, so both import and export systems are operating. The important consideration in these habitats is the final balance or net energy flow, which reflects whether an area has to import or is able to export energy to maintain its condition.

A hypothesis arising from the considerations of temporal and spatial food availability and general net energy flow is that a considerable proportion of the plant material utilized by biological assemblages in Lower Cook Inlet probably originates in the rocky intertidal and subtidal habitats in Kachemak Bay and the southern Kenai Peninsula. The other major sources of potential nutrients are (1) phytoplankton, (2) organic material entrained from the western Gulf of Alaska and the Barren Island, (3) the limited macrophyte material produced on the western shoreline and (4) organic debris of terrestrial origin, entrained in river runoff.

This hypothesis produces some important questions. In order to assess the potential impacts of development in Lower Cook Inlet, it becomes important to know the proportions of nutrient materials contributed seasonally by the indicated sources. It is crucial to identify the source of the nutrient materials utilized in winter and early spring, when contributions from phytoplankton and terrestrial debris are probably negligible. It is particularly important for the western side of the inlet since our observations indicate that macrophytes are absent in the winter.

Presently, knowledge of the net transport patterns in Lower Cook Inlet is very incomplete and provides little assistance in assessing the importance of the various food sources or the possible nutrient transport patterns. (Furthermore, spill trajectories cannot be adequately predicted with existing information) (Dr. R. C. Miller, personal communication).

Considerations of energy production and utilization in Lower Cook Inlet are of high importance. At the very least, the plant production of Kachemak Bay and the southern Kenai Peninsula contribute heavily to the richness of Kachemak Bay. Maximally, it may be of major importance to the total inlet system. In any case, it is a matter of considerable importance in the planning and development of Lower Cook Inlet because it effects the general condition of the biological systems and the fishing industry of that area.

LITERATURE CITED

DAMES & MOORE, 1976. The epifaunal assemblage in the Phillips petroleum lease site off Spring Point, Chinitna Bay, Alaska. Final Report. For Phillips Petroleum Company). 42 pp.

_____________ 1976a. Marine plant community studies, Kachemak Bay, Alaska. Final Report. For Alaska Department of Fish and Game. 288 pp.

_____________ 1977. An ecological assessment of the littoral zone along the outer coast of the Kenai Peninsula for State of Alaska, Department of Fish and Game. Final Report. 101 pp., Appendices A through D.

FISHER, W. K., 1930. Asteroidea of the North Pacific and adjacent waters. U.S.N.M. Bull. 76, Part 3. Forcipulata. 356 pp.

LEES, D. C., 1970. The relationship between available food and movement in the sea urchins, Strongylocentrotus franciscanus and S. purpuratus. Master's Thesis, San Diego State College, 119 pp.

MacGINITIE, G. E., 19755. Distribution and ecology of the marine invertebrates of Point Barrow, Alaska. Smithsonian Misc. Coll. 128(9): 201 pp.

MANN, K. H. 1972. Ecological energetics of the seaweed zone in a marine bay on the Atlantic coast of Canada. II. Productivity of the seaweeds. Marine Biology 14: 19-209.

McROY, C. P. 1972. On the biology of eelgrass in Alaska. Univ. of Alaska. Inst. of Mar. Sci: Rept. No. 72-1:1-156.

NOAA, 1972. Sea ice conditions in the Cook Inlet, Alaska during the 1970-71 winter. NOAA Tech. Memo. AR 7:1-16.

_____________ MS. Sea ice conditions in the Cook Inlet, Alaska during the 1973-/4 winter. NOAA Tech. Memo. NWC AR-8.

ORTH, F. L., C. Smelcer, H. M. Feder and J. Williams, 1975. The Alaska clam industry: A survey and analysis of economic potential. Institute of Marine Science, University of Alaska, IMS Report No. R75-3.

OSBURN, R. C., 1950. Bryozoa of the Pacific coast of America, Part 1, Cheilostomata-Anasca. Allan Hancock Pacific Exped. 14(1): 269 pp.

_____________ 1953. Ibid. Part 3. Cyclostomata, Ctenostomata, Entoprocta and Addenda. Allan Hancock Pacific Exped. 14(3): 841 pp.

PAINE, R. T., 1966. Food web complexity and species diversity. American Naturalist 100: 65-75.

ZOBELL, C. E. 1959. Factors affecting drift seaweeds on some San Diego beaches. Univ. of Calif., Inst. Mar. Resources Rept. No. 59-3:116 pp.

APPENDIX A

SPECIES COMPOSITION AND DISTRIBUTION OF BIOTIC ASSEMBLAGES AT SURVEY SITES ON EAST SIDE OF LOWER COOK INLET

APPENDIX A-1

Mud Bay, Homer	7/13/76	Tide: -3.3 feet at 1020

Location: East of wooded island on east side of Homer Spit, about 1.5 mile out on spit.

Mean Sea Level to +2 feet Consolidated gravel/silt slope

ALGAE-Phaeophyta		
Chorda filum	abundant	stringy, branched
Scytosiphon lomentaria	abundant	combined cover of about 80%
ANGIOSPERMAE		
Zostera marina	uncommon	juvenile turions in drain channels
ANNELIDA-Polychaeta		
Abarenicola pacifica	abundant	∿300/sq m in areas with surface water
ANTHROPODA-Crustacea		
Balanus crenatus	common	on ridges
B. glandula	abundant	on ridges
MOLLUSCA-Pelecypoda		
Mya ?arenaria	common	buried in gravel
M. truncata	common	buried in gravel
Mytilus edulis	common	buried in gravel

+2 to Mean Lower Low Water Gravel and mud slope

ALGAE-Phaeophyta		
Chorda filum	abundant	in channels
Laminaria saccharina	uncommon	in pools
Scytosiphon lomentaria	abundant	in channels

ALGAE-Chlorophyta		
?Monostroma sp.	common	
ANGIOSPERMAE		
Zostera marina	uncommon	
NEMERTEA		
Paranemertes peregrina	common	crawling in surface water
ANNELIDA-Polychaeta		
Abarenicola pacifica	abundant	spawning
ECHIURA		
Echiurus echiurus alaskanus	uncommon	
MOLLUSCA-Pelecypoda		
Macoma balthica	common	
Mya ?arenaria	common	
Mytilus edulis	common	scattered clumps of large individuals
MLLW to -3.5 feet	Scattered boulders	
ALGAE-Phaeophyta		
Fucus distichus	common	young plants
ALGAE-Rhodophyta		
Porphyra sp.		
ARTHROPODA-Crustacea		
Balanus glandula	abundant	
MOLLUSCA		
Littorina sitkana	common	
Mytilus edulis	common	

MLLW to -3.5 feet	Soft, sticky mud over gravel, H_2S near surface	
ALGAE-Chlorophyta		
Enteromorpha linza	uncommon	
Enteromorpha tubulosa	abundant	long filamentous species
?*Ulva* sp.	uncommon	
ALGAE-Phaeophyta		
Alaria sp.	uncommon	drift
Chordaria flagelliformis	uncommon	attached to stones
L. saccharina	common	attached to stones
ANGIOSPERMAE		
Zostera marina	locally abundant	patches of adults
CNIDARIA		
Anthopleura artemisia	uncommon	
NEMERTEA		
Nemertea, unid	common	burrowing, small, white
Paranemertes peregrina	common	
ANNELIDA-Polychaeta		
Abarenicola pacifica	common	
Eteone pacifica	common	
Maldanidae, unid	uncommon	fragment
Nephtys caeca	common	
Nereis ? *virens*		
Polychaeta #1		undetermined family
Polynoidae, unid	uncommon	large burrowing species, fragment
ECHIURA		
Echiurus echiurus alaskanus	common	

ARTHROPODA-Crustacea		
Balanus crenatus	common	on shell and rocks
Crangonidae, unid	uncommon	
MOLLUSCA		
Clinocardium ? *nuttalli*	common	evidence of gull predation; shell only
Littorina sitkana	common	on shell and rocks
Macoma balthica	abundant	near surface
Mya ? *arenaria*	uncommon	
Mytilus edulis	common	evidence of gull predation, scattered groups of 2-6 with individuals up to 10 cm long
Protothaca staminea	uncommon	in gravel patches

Appendix A-1a. Density of *Mya* sp. and percent cover by *Mytilus edulis* in mid intertidal zone at Mud Bay, Homer, 7/13/76

Quadrat	Number of *Mya*	Percent cover of *Mytilus edulis*
1	0	15
2	3	3
3	1	0
4	6	16
5	3	0
6	0	4
7	2	1
8	1	5
9	0	0
10	0	15
11	0	15
12	0	10
13	1	2
14	4	10
15	0	1
16	0	0
17	0	2
18	2	15
19	1	2
20	0	0
$\overline{x}$	1.2	3.5
s	1.7	5.1
Estimated number/sq. m.	4.8	

APPENDIX A-2

Base of Homer Spit 5/13/76 Tide: -5.2 feet at 0748

Location: Near the base of Homer Spit on west side.

MSL to MLLW (about +1.2 m)	Cobble shield	
ALGAE		
Agarum cribrosum	uncommon	on cobble
Fucus distichus	uncommon	small, on cobble
CNIDARIA		
Anthopleura ?xanthogrammica	common	under loose rocks
ANNELIDA-Polychaeta		
Nereis vexillosa	common	under consolidated cobble
Harmothoe imbricata	uncommon	under cobble
Scolelepis sp.	common	under cobble
ARTHROPODA-Crustacea		
Anisogrammarus ?confervicolus	common	under cobble
Anisogammarus ?pugettensis	common	under cobble
Atylus ?collingi	uncommon	under cobble
Lamprops quadraplicata		in lowest sand cover
Maera loveni		juvenile
Oedicerotidae, unid.		juvenile
Paraphoxus obtusidens	uncommon	in sand channels
Near MLLW	Clear sand with coal chips	
ANNELIDA-Polychaeta		
Nephtys parva	common	

ARTHROPODA-Crustacea		
Cumacea, unid #1	common	
Monoculodes sp.	uncommon	
Paraphoxus obtusidens	common	
About 3 to 4 feet	_Silty sand_	
CNIDARIA		
Anthopleura artemisia	uncommon	burrowing in sand
ANNELIDA-Polychaeta		
Arctonoe vittata	uncommon	commensal on asteroids
Nephtys nr. _caeca_	common	
Soloplos armiger	common	
Spiophanes bombyx	common	
Scolelepis sp.	common	most dense about 15 cm below surface
MOLLUSCA		
Clinocardium nuttalli	uncommon	
Macoma ? _lama_	uncommon	
Psephidia lordi	uncommon	
Spisula polynyma	uncommon	
Zirphaea pilsbryi	uncommon	burruowed in packed sand
ARTHROPODA-Crustacea		
Crangon alaskensis	common	
Cumacea, unid	abundant	
Eohaustorius spp.	common	
Hippomedon sp. A	abundant	
Monoculodes sp.		
Paguridae, unid	uncommon	
Paraphoxus obtusidens	uncommon	

ECHINODERMATA-Asterozoa		
Asterias amurensis	uncommon	drift
Leptasterias hexactis	uncommon	drift
CHORDATA-Pisces		
Ammodytes hexapterus	common	in moist surface sand

APPENDIX A-3

Bishop's Beach	5/13/76	Tide: -5.2 feet at 0748

Location: Beach in front of the Seafair Motel, Homer

Near MSL	Unconsolidated silty sand and mud	
CNIDARIA-Anthozoa		
Anthopleura artemisia	common	
ANNELIDA-Polychaeta		
Abarenicola pacifica	abundant	in seep water areas
ARTHROPODA-Crustacea		
Anonyx sp. A	uncommon	
Near MSL	Boulders	
ALGAE		
Fucus distichus	abundant	
?*Melanosiphon* sp.	common	
Rhodomela larix	common	
Scytosiphon lomentaria	abundant	
Ulothrix sp.	abundant	on *Fucus*
Urospora sp.	common	
NEMERTEA		
Paranemertes peregrina		
ANNELIDA-Polychaeta		
Eteone nr. *longa*		

ARTHROPODA-Crustacea		
Anisogammarus ? pugettensis		
Anonyx sp. B		
Balanus cariosus	common	low on rock
B. crenatus	common	low on rock
B. glandula	abundant	on sides and tops of rocks
Caprella cf. borealis		on seaweed
Chthamalus dalli	abundant	
Gnorimosphaeroma oregonensis	common	under rocks
Idothea fewkesi	common	under Fucus
MOLLUSCA		
Acmaeidae, unid	common	prob. collisella pelta and Notoacmea persona
Littorina sitkana	common	
Mytilus edulis	abundant	heavy new set; adults to 35 mm
Nucella emarginata	common	concentrated under overhangs; feeding heavily on Balanus sp. and young Mytilus
MLLW to -4 feet	Sand	
ECHIURA		
Echiurus echiurus alaskanus	uncommon	about 30 cm below surface
ANNELIDA-Polychaeta		
Magelona sacculata	common	in sand tubes
Nephtys nr. caeca	common	
Nephtys nr. parva	uncommon	

Nerine foliosa	uncommon	very large
Spiophanes bombyx	common	about 15 cm below surface
ARTHROPODA-Crustacea		
Cumacea, unid	uncommon	
Eohaustorius spp.	common	
Hippomedon sp. A	abundant	
Paraphoxus obtusidens	uncommon	
P. o. major		
MOLLUSCA		
?*Macoma* spp.	uncommon	
Siliqua alta	uncommon	below about -4 feet
Spisula polynyma	common	below about -4 feet
Tellina lutea	common	below about -3 feet
UROCHORDATA		
Ritterella pulchra	uncommon	drift
CHORDATA-Pisces		
Ammodytes hexapterus	common	in most sand surface

APPENDIX A-4

West of Bishop's Beach | 5/15/76 | Tide: -5.7 feet at 0919

Location: Boulder bench about 1 mile west of Seafair Beach, Homer.

Above MSL	Boulders and Cobbles	
ARTHROPODA-Crustacea		
Anisogammarus ? pugettensis	abundant	under rock
Balanus glandula	common	under rock, adults and new set
Gnorimosphaeroma oregonensis	abundant	under rock
Between MSL and MLLW	Boulders	
ALGAE		
Fucus distichus	abundant	on large boulders
Scytosiphon ? lomentaria	abundant	on sides of large boulders
Ulothrix sp.	common	on Fucus
Urospora sp.	abundant	on tops of smaller scoured boulders
NEMERTEA		
Paranemertes peregrina	uncommon	among barnacles and mussels
ANNELIDA-Polychaeta		
Eteone nr. longa	common	among barnacles and mussels
ARTHROPODA-Crustacea		
Anisogammarus ? pugettensis	abundant	under cobble
Balanus glandula	abundant	
Calliopiella sp.		

Caprella cf. *borealis*	common	on algae
Chthamalus dalli	abundant	
Gnorimosphaeroma oregonensis		
Idothea fewkesi	common	on *Fucus*
MOLLUSCA		
Collisella pelta	common	
Littorina sitkana	abundant	
Mytilus edulis	common	small
Between MSL and MLLW	In silty sand between boulders	
CNIDARIA-Anthozoa		
Anthopleura artemisia	common	
ANNELIDA-Polychaeta		
Abarenicola pacifica	abundant	in localized patches
About MLLW[1]	Large boulder	
ALGAE-Chlorophyta		
Cladophora sp.		
Ulothrix sp.	common	on *Fucus*
Urospora sp.	common	on scoured rocks
ALGAE-Phaeophyta		
Fucus distichus	common	
?*Melanosiphon* sp.	common	
Scytosiphon lomentaria	common	
PORIFERA		
Halichondria panicea	common	on sides of rocks

[1] Also present were other species described on upper boulders

ANNELIDA-Polychaeta		
<u>Harmothoe imbricata</u>	uncommon	under boulder
ARTHROPODA-Crustacea		
<u>Balanus glandula</u>	abundant	
<u>Balanus cariosus</u>	abundant	very large individuals
<u>Chthamalus dalli</u>	abundant	dense where <u>B. cariosus</u> knocked off rocks
MOLLUSCA		
<u>Littorina sitkana</u>	abundant	
<u>Mytilus edulis</u>	abundant	very large individuals
<u>MLLW to -5.5 feet</u>	<u>Boulder bench and tide pools</u>	
ALGAE-Phaeophyta		
<u>Agarum cribrosum</u>	abundant	dominant; 10% cover
<u>Desmarestia</u> ? <u>viridis</u>		
ALGAE-Rhodophyta		
<u>Ahnfeltia plicata</u>	common	
<u>Callophyllis</u> ? <u>pikeanum</u>	common	
<u>Erythroglossum</u> sp.		
<u>Gloiopeltis furcata</u>		
<u>Hymenema setchelli</u>		
<u>Iridaea</u> sp.		
<u>Lithophyllum</u> sp.	common	encrusting rocks on
<u>Lithothrix</u> ? <u>aspergillum</u>	uncommon	on top of rocks
<u>Opuntiella</u> sp.		
<u>Polysiphonia</u> ? <u>collinsi</u>	common	
<u>Ptilota tenuis</u>		
<u>Rhodomela larix</u>		
<u>Rhodymenia palmata</u>		

PORIFERA

?*Esperiopsis laxa*	uncommon	
Halichondria panicea	abundant	yellow, channelled on sides on rocks
Haliclona permollis	common	gray-white, osculate; on rocks
?*Microciona* sp.	common	thin, orange; sides of rocks
Mycale ? *lingua*		
Myxilla incrustans		

CNIDARIA

Abietinaria ? *costata*	common	on rocks; immature
Abietinaria turgida	abundant	on rocks in pools
Anthopleura artemisia	abundant	about 1 sq m in tubicolous polychaeta bed and silty pockets
Campanularia urceolata	common	on *A. turgida*
Cribrinopsis similis	common	large, yellow; feeding on sea urchins
Eudendrium vaginatum	common	on rocks in pools
Gersemia rubriformis	uncommon	in lowest pools
Sertularella tricuspidata		on *A.turgida*
Tealia crassicornis	common	

ANNELIDA-Polychaeta

Arctonoe vittata	uncommon	
Crucigera zygophora	common	encrusting tops of low boulders
Eunoe orsetedi	uncommon	on lowest boulders
Glycera capitata	common	in silty areas
Nereis pelagica	common	under rock in burrows in silt

Nicomache personata	common	sand tubes on rock
Owenia collaris	common	sand tubes among *S. insignis*
Pectinaria (C.) granulata	common	sand tubes among S. *insignis*
?*Potamilla* nr. *reniformis*	uncommon	
Sabella crassicornis	common	on rock and among *S. insignis*
Schizobranchia insignis	abundant	forming extensive sand mats
Spirorbis ? *semidentatus*	abundant	on and under low rocks
SIPUNCULIDA		
Golfingia sp.	uncommon	under rocks
ARTHROPODA-Crustacea		
Balanus cariosus	abundant	very large individuals on inner edge of bed
B. crenatus	abundant	
B. glandula	abundant	
B. nubilus	uncommon	on lowest rocks
B. rostratus	common	
Calliopiella sp.	common	
Crangon alaskensis	common	in pools
C. stylirostris	common	in pools
Elassochirus gilli	uncommon	
E. tenuimanus	common	
Hippomedon sp. A	uncommon	
Lebbeus sp.		in pools
Mysidacea, unid	common	
Oregonia gracilis	common	in pools and under rocks
Pagurus beringanus	common	in pools
Pugettia richii		

MOLLUSCA-Gastropoda

Collisella pelta	uncommon	
Dendronotus sp.	uncommon	in pools
Fusitriton oregonensis	uncommon	in sandy areas
Neptunea lirata	common	spawning
Notoacmea persona		
N. scutum	common	
Trichotropis insignis	uncommon	

MOLLUSCA-Pelecypoda

Clinocardium ? *nuttalli*	common	in silty areas
Hiatella arctica	common	under rocks and among *Schizobranchia*
Humilaria kennerlyi		shell only
Modiolus modiolus		shell only
Mya? *arenaria*	uncommon	in silty areas
M. truncata	common	among rocks and *Schizobranchia*
Mytilus edulis	common	on tops of isolated boulders
Protothaca staminea		shells only
Saxidomus giganteus		shells only
Zirfaea pilsbryi	common	burrowing in rocks and hard-pan, often under *Schizobranchia*

MOLLUSCA-Polyplacophora

Mopalia lignosa	common	
M. ? *mucosa*	common	
Tonicella insignis	common	

BRYOZOA

Alcyonidium pedunculatum	common	under large, unsettled boulders
A. polyoum	common	encrusting cobbles and boulders
Bidenkapia spitsbergensis		
Caulibugula sp.	abundant	unreported species in pools
Crisia ? *eburnea*		reproductive
Dendrobeania murrayana	common	under unsettled boulders and in crevices
Hippothoa hyalina	abundant	on *Ahnfeltia*, reproductive
Terminoflustra membranaceo-truncata	common	reproductive, on sides of and under unsettled boulders

ECHINODERMATA-Asterozoa

Asterias amurensis	common	on rocks and pavement
Evasterias troschelii	abundant	on rock bench
Leptasterias hexactis Forma *regularis*	common	under rocks, brooding
L. polaris acervata	abundant	on rocks and pavement
L. p. katherinae	uncommon	in drift
Ophiopholis aculeata	abundant	under rocks
Pycnopodia helianthoides	uncommon	
Solaster stimpsoni	uncommon	in crevices

ECHINODERMATA-Echinoidea

Strongylocentrotus drobachiensis	abundant	dominate herbivore on lowest bench; about 13/sq m
S. ? *pallidus*	common	

ECHINODERMATA-Holothuroidea		
Chiridota sp.	common	under rocks
Cucumaria sp.	uncommon	small brown species
Eupentacta ? *quinquesemita*	uncommon	
UROCHORDATA		
Halocynthia aurantia	uncommon	
CHORDATA-Pisces		
Microgadus proximus	uncommon	in pools
Pleuronectiformes, unid.	uncommon	in pools

Appendix A-4a. Size data for *Strongylocentrotus* spp. collected from a 1 x 6.5 m. plot on low bench 1 mile W. of Seafair Beach, 5/15/76.

Test Diameter (mm)	Frequency	Test Diameter (mm)	Frequency
8	1	30	9
10	1	31	8
11	1	32	7
12	3	33	1
13	2	34	5
17	1	35	4
18	3	36	4
20	3	37	1
21	4	38	3
22	2	39	1
23	4	40	2
26	2	47	1
27	5	49	1
28	4	50	1
29	2		

n 86

$\bar{x}$ 28.4

s 8.5

no./sq. m. 13.2

APPENDIX A-5

Whiskey Gulch 5/12/76 Tide: -3.8 feet at 0700

Location: 1 mile south of access road

MLLW	Cobble	
ARTHROPODA-Crustacea		
Ampelisca ? *eschrichtii*	common	in surface water
Anisogammarus ? *pugettensis*	abundant	very abundant under cobble
Pagurus ochotensis	uncommon	in tidepool
Telmessus cheiragonus	uncommon	among cobbles and burrowing among sand pockets
CHORDATA-Pisces		
Cottidae, unid	uncommon	in tide channel
Liparis rutteri	uncommon	under rocks
-1 to -3.5 feet	Sand	
ALGAE-Phaeophyta		
Alaria ? *praelonga*	common	adults and juveniles
Desmarestia ? *viridis*	uncommon	
Laminaria groenlandica	common	adults
L. saccharina	common	adults and juveniles
ANNELIDA-Polychaeta		
Abarenicola pacifica	locally abundant	
Nephtys nr. *ciliata*	common	

Scolelepis sp.	abundant	
Scoloplos armiger	common	
Spio butleri	uncommon	
ARTHROPODA-Crustacea		
Anisogammarus ? *pugettensis*	common	in surface water
Anonyx sp. A	common	
Cumacea, unid	uncommon	
Eohaustorius spp.	abundant	
Lamprops quadriplicata		
Pagurus ochotensis	uncommon	
Paraphoxus obtusidens major	abundant	ovigerous
Telmessus cheiragonus	uncommon	partially buried at waterline
MOLLUSCA		
Macoma expansa	uncommon	
Saxidomus giganteus		shell only
Siliqua patula	uncommon	
Spisula polynyma	common	
Tellina lutea		shell only
BRYOZOA		
Alcyonidium pedunculatum	common	attached to pebbles
ECHINODERMATA		
Leptasterias hexactis	uncommon	dirft
CHORDATA-Pisces		
Ammodytes hexapterus	common	

Near MLLW — On or Around boulders

ALGAE-Chlorophyta

?*Monostroma* sp.

ALGAE-Phaeophyta		
Alaria ? *praelonga*	common	on sand
Desmarestia viridis	uncommon	on sand
?*Ilea* sp.	common	on rock
Laminaria groenlandica	common	on sand
L. saccharina	common	juveniles on sand
Pylaiella littoralis	common	on rock
ALGAE-Rhodophyta		
Polysiphonia ? *pacifica*	abundant	25% cover on rock
Rhodymenia palmata	common	on rock
CNIDARIA		
Anthopleura ? *xanthogrammica*	common	on rock
NEMERTEA		
Paranemertes peregrina	uncommon	among barnacles and mussels
ANNELIDA-Polychaeta		
Cirratulus cirratus cirratus	uncommon	in silty pockets around byssal threads
Eteone nr. *longa*	common	among boulder & mussels
ARTHROPODA-Crustacea		
Anonyx sp. B	uncommon	in silty pockets
Balanus crenatus	abundant	
B. glandula	abundant	
Paraphoxus obtusidens	uncommon	
MOLLUSCA		
Acmaea pelta	common	
Mytilus edulis	abundant	25% cover; heavy 1-year class, length to 10 cm
Notoacmaea scutum	common	

BRYOZOA		
Hippothoa hyalina	common	on rock and barnacles
Tegella robertsonae	common	on rock
ECHINODERMATA-Asterozoa		
Leptasterias hexactis	common	feeding on *Balanus* and a gammarid

APPENDIX A-6

Deep Creek 5/17/76 Tide: -3.4 feet at 1052

Location: South from access road, within 1 mile.

MLLW to -3.5 feet	Sand with coal chips	
ANNELIDA-Polychaeta		
Eteone nr. longa	uncommon	
Nephtys nr. caeca	common	
Nereis sp.	common	epitokes on sand surface
Paraonidae unid.	common	very small individuals
Pionosyllis magnifica	uncommon	
Scolelepis sp.	common	
Scoloplos armiger	common	larger individuals in runoff channels
? Spio filicornis	common	small individuals
MOLLUSCA-Pelecypoda		
Spisula polynyma	uncommon	major densities below -3.5 feet
Siliqua patula	uncommon	major densities below -3.5 feet
ARTHROPODA-Crustacea		
Ampelisca ? eschrichtti	common	
Anisogammarus ? confervicolus	common	in surface runoff
Anisogammarus ? pugettensis	abundant	in surface runoff
Anonyx sp. A	uncommon	
Eohaustorius spp.	abundant	
Ericthonius sp.	uncommon	

Pagurus kennerlyi	uncommon	in pool
Paraphoxus obtusidens	uncommon	
P. o. major	uncommon	
CHORDATA-Pisces		
Ammodytes hexapterus	common	buried in most surface sand
About MSL	Boulders	
MOLLUSCA		
Littorina sitkana	abundant	
Mytilus edulis	common	
Notoacmaea ?scutum	common	
ARTHROPODA-Crustacea		
Balanus crenatus	common	lower boulders
Balanus glandula	abundant	mid-upper boulders with new set

APPENDIX A-7

Clam Gulch	5/14/76	Tide: -5.8 feet at 0833

Location: From access road 1.0 mile south

-2 feet	Sand	
ANNELIDA-Polychaeta		
Paraonidae, unid.	common	very tiny individuals
Scolelepis sp.	uncommon	
Nephtys nr. *parva*	common	
Nephtys nr. *schmitti*	uncommon	
ARTHROPODA-Crustacea		
Crangon alaskensis	uncommon	
Eohaustorius spp.	abundant	
Paraphoxus obtusidens major	uncommon	
-4 feet	Silty Sand	
CNIDARIA-Anthozoa		
Anthopleura artemisia	common	
Tealia crassicornis	uncommon	large, attached to rock
ANNELIDA-Polychaeta		
Abarenicola pacifica	locally common	in scour depressions around boulders
Lumbrineris ? *luti*	uncommon	
Nephtys nr. *caeca*	common	very large
Notomastus lineatus	uncommon	

Scolelepis nr. *squamatus*	abundant	
Scoloplos armiger	common	
Spio filicornis	common	
Terebellides stroemi	abundant	in lowest mud
ARTHROPODA-Crustacea		
?*Ampithoe* sp.		
Balanus hesperius	uncommon	on *Neptunea* shell
Chionocetes bairdi	common	near water line
Crangon ? *alaskensis*	common	
Eohaustorius spp.	abundant	
Gammaridea #3	uncommon	
Pagurus ochotensis	uncommon	
MOLLUSCA		
Clinocardiun nuttalli	common	
Fusitriton oregonensis		
Macoma #1	uncommon	
Neptunea lirata	uncommon	
Siliqua patula	abundant	densities to near $1/m^2$
Spisula polynyma	common	small individuals
BRYOZOA		
Alcyonidium enteromorpha	common	attached to buried pebbles

Above MLLW	On boulders	
ARTHROPODA-Crustacea		
Balanus crenatus	abundant	lower rocks
Balanus glandula	abundant	upper rocks
MOLLUSCA		
Mytilus edulis	common	scattered small individuals
Nucella emarginata	common	feeding on *Balanus*
CHORDATA-Aves		
Larus glaucescens (Glaucous-winged gull)	common	
Melanitta perspicillata (surf scoter)	common	offshore

Appendix A-7a. Shell length data for the razor clam *Siliqua patula* from Clam Gulch, 5/14/76.

Shell length (mm)	Frequency	Shell length (mm)	Frequency
94	1	126	4
105	1	127	5
110	1	128	3
112	1	129	3
114	2	130	4
116	1	132	1
118	1	133	3
119	1	134	2
120	2	135	5
122	5	137	1
124	1	138	1
125	3	145	1

$\overline{x} \pm s = 125.9 \pm 8.8$

$n = 53$

APPENDIX A-8

Kasilof Beach 5/17/76 Tide: -3.4 feet at 1052

Location: About 0.25 mile north of Kasilof River mouth.

Above MLLW	Clayey mud at base of sand and dunes	
ANNELIDA-Polychaeta		
Abarenicola pacifica	uncommon	
MOLLUSCA-Pelecypoda		
Macoma balthica	common	burrowing 15-30 cm. in sediment, pink and white forms

APPENDIX B

SPECIES COMPOSITION AND DISTRIBUTION OF BIOTIC ASSEMBLAGES AT SURVEY SITES ON WEST SIDE OF LOWER COOK INLET

APPENDIX B-1

Douglas River — 6/15/76 — Tide: -3.3 feet at 1031

Location: About 2.5 miles west of Douglas River mouth.

MSL	Upper rock bench	
ALGAE-Chlorophyta		
Chlorophyta, unid	abundant	short, filamentous on scoured upper surfaces
Cladophora sp.		
Enteromorpha sp.	common	in channels and pools
Spongomorpha sp.	abundant	in channels and pools
?*Monostroma* sp.	common	in channels and pools
Ulothrix sp.		
ALGAE-Phaeophyta		
Fucus distichus	common	around channels and pools
Phaeophyta, unid	common	stringy, filamentous
Pylaiella littoralis	abundant	in pools
Scytosiphon lomentaria	common	stunted; in pools
ALGAE-Rhodophyta		
Rhodomela larix	common	in pools
ANGIOSPERMAE		
Zostera marina	common to abundant	young plants; in pools and channels
ARTHROPODA-Crustacea		
Anisogammarus ? *confervicolus*	uncommon	in pools
Balanus glandula	very abundant	spot very abundant; adults common, only in protective depressions

MOLLUSCA

Littorina sitkana	abundant	in protected depressions spawning under rocks
Macoma balthica	abundant	in silt in channels
Mya ? arenaria	abundant	in deep silt in channels
Mytilus edulis	uncommon	juveniles in protected channels
Nucella lima	uncommon	under rock

<u>MSL to about MLLW</u>   <u>Lower rock bench</u>

ALGAE-Chlorophyta

Spongomorpha sp.	abundant	
?*Monostroma* sp.		

ALGAE-Phaeophyta

Fucus distichus	common	in pools
Laminaria saccharina	uncommon	in large, deep pools
Pylaiella littoralis	common	in pools
Scytosiphon lomentaria	abundant	in pools and channels

ALGAE-Rhodophyta

Ceramium sp.		
?*Gracilariopsis* sp.		
Odonthalia floccosa		
Rhodomela larix	common	in pools

ANGIOSPERMAE

Zostera marina	common to abundant	young plants; in pools and channels

PORIFERA

?*Halichondria* sp.	common	under rocks

CNIDARIA

Anthopleura ? xanthogrammica	common	under rocks
Obelia ? longissima	common	on sides of and under rocks

ANNELIDA-Polychaeta

Abarenicota pacifica	common	in silty pockets
Ampharete acutifrons	uncommon	under rocks
Autolytus prismaticus	uncommon	on Halichondria
Capitella capitata	uncommon	among algae (?)
Eteone sp. A.	common	under rock
Harmothoe imbricata	common	under rocks; none collected
Naineris quadricuspida	common	under rocks; none collected

ARTHROPODA-Crustacea

Achelia ? chelata	uncommon	among algae
Ampithoe sp.	common	under rocks
Anisogammarus ?confervicolus	abundant	under rocks
Balanus glandula	very abundant	new set and adults
Caprella borealis	abundant	on algae
C. drepanochir		on algae
Gnorimosphaeroma oregonensis	abundant	under rocks
Idothea ochotensis	common	under rock; with young
Pagurus hirsutiusculus	common	under rock and in pools

MOLLUSCA

Collisella ? pelta	common	under rocks and on vertical slopes
Littorina sitkana	abundant	
Macoma balthica	abundant	
Mopalia lignosa	common	under rocks

Mya ? _arenaria_	abundant	in silt pockets and channels
Mytilus edulis	common	mainly juveniles
Nucella lima	common	spawning under rocks
Schizoplax brandtii		
ARTHROPODA-Insecta		
Tendipedidae (larvae)	common	among algae
BRYOZOA		
Bryozoa, unid	common	encrusting under rocks
Eucratea loricata	common	on boulders and rocks
ECHINODERMSTA		
Chiridota sp.	common	under rock
?_Evasterias_ sp.	very uncommon	juvenile (?)
Leptasterias hexactis	very uncommon	under rock
CHORDATA-Pisces		
Pholis laeta	common	under rock
MSL to MLLW	_Mud_	
CNIDARIA		
Actiniaria, unid	uncommon	small, white burrowing species
Anthopleura artemisia	common	
NEMERTEA		
Cerebratulus ?_marginata_	uncommon	burrowing
ANNELIDA-Polychaeta		
Abarenicola pacifica	abundant	
Nephtys nr. _caeca_	common	

ECHIURA		
Echiurus echiurus alaskanus	common	
MOLLUSCA-Pelecypoda		
Macoma balthica	abundant	to 100/0.25 sq. m.
Mya ?_arenaria_	abundant	to 80/0.25 sq. m.
?_Orobitella rugifera_	uncommon	in _Echiurus_ burrow
MLLW to -3 feet	Brown Sand Bar	
CNIDARIA		
Anthopleura artemisia	uncommon	in siltier areas
ANNELIDA-Polychaeta		
Eteone nr. _longa_	uncommon	in cleaner sand
Nephtys nr. _caeca_	common	in siltier areas
Phyllodoce (Anaitides) groenlandica	common	in cleaner areas
Scolelepis sp.	common	in cleaner sand
MOLLUSCA		
Clinocardium sp.	uncommon	
Macoma balthica	uncommon	
Mya ?_arenaria_	common	near freshwater runoff channels
Mya ?_elegans_	locally common	very large individuals in siltier areas
Siliqua alta	uncommon	in siltier areas
Siliqua patula	common	to near 1.0 sq. m.
Spisula polynyma	common	generally less dense
Tellina lutea	uncommon	
ARTHROPODA-Crustacea		
Crangon alaskensis	uncommon	near freshwater runoff
Saduria entomon	common	in silty surface layer near bench and runoff

APPENDIX B-2

Amakdedori Beach 7/13/76 Tide: -3.7 ft at 0930

Location: About 1 mile south of Amakdedori Creek

MLLW to -3 ft	Sand	
NEMERTEA		
Paranemertes peregrina	uncommon	
ANNELIDA-Polychaeta		
Abarenicola pacifica	common	MLLW
Arenicola marina	uncommon	
Nephtys nr. ciliata	uncommon	
Orbiniella nuda	uncommon	northern range extension
Scolelepis sp.	abundant	in silty areas near rock
?*Spio* sp.	abundant	burrowing about 15 cm deep
MOLLUSCA		
Siliqua patula	abundant	newly set
PYCNOGONIDA, UNID.		under drift algae
ARTHROPODA-Crustacea		
Amphitoe sp		under drift algae
Anisogammarus ?*pugettensis*	abundant	under drift algae
Batea sp		under drift algae; juvenile
Caprella sp.		under drift algae; juveniles
Ischyrocerus sp.		under drift algae; juvenile
Telmessus cheiragonus	common	in silt near rock
Gammarus sp. A.		

+2 to -3 ft	Rock Bench	
ALGAE-Chlorophyta		
Cladophora sp.		
?*Monostroma* sp.		
Ulothrix sp.		
ALGAE-Phaeophyta		
Cystoseira geminata		drift
Fucus distichus	common	small young plants
ALGAE-Rhodophyta		
Ahnfeltia plicata	common	
Callophyllis sp.	abundant	
Ceramium eutonianum		
Ceramium sp.		
encrusting coralline alga	uncommon	in tide pools
Phycodrys sp.		epiphytic on *Ahnfeltia*
Polysiphonia hendryi var. *gardneri*	common	in tide pools
Rhodomela larix	common	
Rhodymenia palmata		
?*Rhodymenia* sp.		
PORIFERA		
Halichondria ? *panicea*	common	under rock
CNIDARIA		
Anthopleura xanthogrammica	common	in pools and under rock
Plumularia magellanica moneroni	common	
ANNELIDA-Polychaeta		
Harmithoe imbricata	common	under rock
ARTHROPODA-Crustacea		
Balanus glandula	very abudant	ubiquitous, newly settled

Pagurus beringanus	common	under rock
Telmessus cheiragonus	common	breeding under rock
BRYOZOA		
Alcyonidium pedunculatum	uncommon	in beach drift
A. polyoum	common	under rock
Flustrella corniculata	common	on *Ahnfeltia*
Hippothoa hyalina	common	on *Ahnfeltia*
ECHINODERMATA		
Leptasterias hexactis	common	under rock
CHORDATA-Pisces		
Pholis laeta	common	under rock

APPENDIX B-3

Bruin Bay	6/14/76	Tide: -4.5 feet at 0949

Location: Rocky Point 2 miles WNW of Contact Point

Above MSL	Rock	
MOLLUSCA		
Littorina sitkana	common	
ARTHROPODA-Crustacea		
Balanus glandula	abundant	dense new set
Chthamalus dalli	common	
Near MLLW to -3 ft		
ALGAE-Chlorophyta		
Chlorophyta, unid	common	on top of low boulders
Enteromorpha intestinalis	common	on top of low boulders
?*Monostroma* sp.	uncommon	
ALGAE-Phaeophyta		
Alaria sp.	common	on low cobble
Fucus distichus	common	on sides of low boulders
Laminaria groenlandica	common	on low cobble
L. saccharina	abundant	on low cobble
Scytosiphon lomentaria	common	on low cobble
ALGAE-Rhodophyta		
encrusting coralline, unid	common	in pools
Halosaccion glandiforme	uncommon	
Odonthalia kamschatica	common	on sides of low boulders

Rhodophyta, unid	common	filamentous; in pools
Rhodymenia palmata	common	on sides of low boulders
ANGIOSPERMAE		
Zostera marina	uncommon	in small pools
PORIFERA		
Halichondria ? *panicea*	abundant	extensive mats over low cobble
CNIDARIA		
Anthopleura ? *xanthogrammica*	common	under rock
Actiniaria, unid	common	under rock, small white burrowing specimen
Sertulariidae, unid	common	under rock; tiny white
ANNELIDA-Polychaeta		
Eteone sp. A.	common	among barnacles
Fabricia sabella	numerous	tubes forming dense mats, 1-3 ft.
?*Harmothoe imbricata*	common	under rock
ARTHROPODA-Crustacea		
Ampithoe sp. A	uncommon	
Anisogammarus ? *confervicolus*	common	under rock
Balanus glandula	abundant	new set approaching 100 percent cover
Pagurus beringanus	common	under rock
MOLLUSCA		
Littorina sitkana	abundant	
Nucella emarginata	common	
BRYOZOA		
Alcyonidium polyoum	common	under rocks
ECHINODERMATA		
Leptasterias ? *hexactis*	common	under rock

APPENDIX B-4

Bruin Bay	6/14/76	Tide: -4.5 feet at 0949

Location: "Brownie Cove" about 1.5 mi W. of Contact Point

MSL to -3 ft	Fine silty sand with gravel	
ALGAE-Chlorophyta		
Cladophora sp.	common	
?*Monostroma* sp.	common	
ALGAE-Phaeophyta		
Desmarestia aculeata	uncommon	
Laminaria saccharina	common	
Scytosiphon lomentaria	common	
ALGAE-Rhodophyta		
Halosaccion glandiforme	uncommon	
Polysiphonia sp.	common	filamentous
ANGIOSPERMAE		
Zostera marina	very abundant	large bed
CNIDARIA		
Actiniaria, unid	common	small burrower
ANNELIDA-Polychaeta		
Maldanidae, unid	common	
Nephtys nr. *cacae*	common	
ARTHROPODA-Crustacea		
Caprella borealis		
Caprella drepanochir	common	on eel grass
Heptacarpus sp.	uncommon	in sand
Pagurus sp.	uncommon	
Telmessus cheiragonus	uncommon	

MOLLUSCA

Clinocardium ?californiense	uncommon	
?Cyrtodaria kurriana	uncommon	
Macoma balthica	common	many drilled shells
Mya ? arenaria	common	
M. truncata	common	
?Natica sp.	uncommon	egg cases common

MSL to -4 feet — Gravelly sand with silty and scattered boulders

ALGAE-Chlorophyta

Spongomorpha sp.	common	on top of boulders
?Monostroma sp.	common	on west side of boulders

ALGAE-Phaeophyta

Agarum cribrosum	uncommon	
Fucus distichus	common	on north and south ends of boulders
Heterochordaria abietina	uncommon	
Laminaria groenlandica	common	on cobble and around deep boulders
L. saccharina	common	on cobble

ALGAE-Rhodophyta

Callophyllis sp.	common	
encrusting coralline algae	common	
Gloiopeltis furcata	common	
Halosaccion glandiforme	abundant	on west side of boulders
Odonthalia kamschatica	abundant	on west side of boulders
Porphyra sp.	uncommon	
Rhodymenia palmata	abundant	on west side of boulders

PORIFERA		
Halichondria panicea	common	on bases of boulders
Haliclona permollis		
CNIDARIA		
Actiniaria, unid	common	tiny white burrower
Anthopleura artemisia	common	under rock
Obelia longissima	common	on kelphold fasts and large cobbles
ANNELIDA-Polychaeta		
Cirratulus cirratus	common	
Fabriciat sabella	locally abundant	forming dense sandy mats
Maldanidae, unid	common	
Nephtys caeca	common	
Polynoidae, unid	common	under rock
Spirorbis ?spirillum	common	on Fucus blades
Travisia sp.	common	under rock
ECHIURA		
Echiurus echiurus alaskanus	common	
MOLLUSCA		
Clinocardium sp.	common	
Collisella ?pelta	common	on boulders
Lacuna sp.	common	on Laminaria spp.
Macoma balthica	common	
M. obliqua	common	
Margarites helicinus	common	among algae on rock
Musculus ?niger	uncommon	half buried in substrate
Mya ?arenaria	common	
M. truncata	uncommon	

Natica sp.	uncommon	egg cases only
Neptunea lirata	uncommon	egg cases only
Notoacmaea ?scutum	common	on rock
Nucella emarginata		
Protothaca staminea	uncommon	shell only
Saxidomus giganteus	uncommon	shell only
ARTHROPODA-Crustacea		
Ampelisca sp.	uncommon	under rock
Balanus crenatus	common	on rock
Balanus glandula	abundant	on rock
Crangon alaskensis	common	in moist sand
Hapalogaster mertensii	uncommon	small; under rock
Pagurus beringanus	common	under rock
Pagurus hirsutiusculus	uncommon	higher on beach
Telmessus cheiragonus		
BRYOZOA		
Alcyonidium ?pedunculatum	common	
Caulibugula sp.	common	
ECHINODERMATA		
Asteriinae, unid		juvenile on *Halichondria*
Henricia tumida	uncommon	in low runoff channels
Leptasterias polaris acervata	uncommon	on cobble

Appendix B-4a. Density data for _Zostera marina_ in 1/16 sq. m. quadrats, Bruin Bay; 6/14/76.

Number of turions per quadrat	Percent Cover
58	50
12	12
43	25
29	25
78	70
66	70
13	15
18	15
95	75
38	
0	
54	
53	
5	
0	
0	
61	
14	
10	
0	
54	
5	
10	
$\bar{x}$ 31.1	
s 28.7	

Appendix B-4b. Size data, *Zostera marina* from Bruin Bay, 6/14/76.

Length (cm)	29.0	31.0	24.5	28.5	23.5	27.0	21.0	22.0	25.0
Width (mm)	2.5	2.5	2.0	2.0	2.0	2.0	3.0	2.5	2.5

Length (cm)	22.5	26.0	21.5	22.0	18.5	18.0	21.0	21.0	22.0
Width (mm)	2.0	2.0	2.0	3.0	2.0	1.5	2.0	2.0	2.0

Length (cm)	18.5	23.0	22.0	18.0	25.5	25.5	26.0	24.0	19.0
Width (mm)	2.0	2.0	2.0	2.0	2.5	2.5	2.0	2.0	2.0

Length (cm)	25.0	24.0	22.0	21.5	24.0	19.0	26.5	20.5	25.0
Width (mm)	2.5	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0

Length (cm)	25.5	22.0	26.0	24.0	23.0	30.0	17.0	26.0	21.0
Width (mm)	2.0	1.5	3.0	2.0	2.0	2.5	2.0	2.0	3.0

Length (cm)	21.5	23.0	18.0	29.0	22.5	21.0	18.0	27.0	27.0
Width (mm)	2.0	2.0	2.5	2.0	2.5	2.0	1.5	2.0	2.5

Length (cm)	31.0	20.0	22.0	25.0	22.0	28.0	21.0	21.0	26.0
Width (mm)	3.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.5

Length (cm)	25.0	22.0	27.0	36.0	27.0	23.0
Width (mm)	3.0	2.0	2.0	2.5	2.0	2.0

n = 69

$\overline{x} \pm s$(length): 23.6 $\pm$ 3.6

$\overline{x} \pm s$(width): 2.2 $\pm$ 0.3

Appendix B-4c. Mensural data for <u>Zostera marina</u> from Bruin Bay, 6/14/76.

Turion length (cm)	Wet weight of turion (gm)	Dry weight of turion (gm)	Dry/Wet weight
31.5	0.45	0.10	0.222
24.5	0.49	0.09	0.184
22.0	0.24	0.06	0.250
22.5	0.34	0.06	0.176
26.0	1.28	0.18	0.141
30.0	0.65	0.09	0.138
27.0	0.45	0.08	0.178
31.5	0.89	0.14	0.157
28.5	2.07	0.29	0.140
34.0	2.00	0.29	0.145
28.5	0.40	0.06	0.150
24.5	0.64	0.10	0.156
26.5	0.49	0.07	0.143
24.0	0.40	0.06	0.150
27.5	0.50	0.05	0.100
23.5	0.42		
24.0	0.91		
27.5	0.55		
30.0	0.66		
28.5	0.60		
22.0	0.44		
27.0	0.57		
33.5	0.80		
31.0	0.69		
33.0	0.57		
$\bar{x}$	0.70	0.12	0.162
s	0.46	0.08	0.036

* length of longest leaf

APPENDIX B-5

Iniskin Bay	6/12/76	Tide: -5.3 feet at 0820

Location: "Blackie Cove" About 1 mile ENE of Mushroom Islets

MHW	Gravel and clean sand	
ARTHROPODA-Crustacea		
Orchestia sp.	abundant	in algal drift
Near MLLW to -5 feet	Fine mud with few cobble	
ALGAE-Chlorophyta		
?*Monostroma* sp.		
ALGAE-Phaeophyta		
Fucus distichus	common	
Laminaria groenlandica	common	
L. saccharina	common	
Scytosiphon lomentaria	common	
ALGAE-Rhodophyta		
Callophyllis sp.		
Iridaea lineare	common	
Rhodophyta, unid		fleshy
Rhodymenia pertusae		
ANGIOSPERMAE		
Zostera marina	common	in scattered patches
CNIDARIA		
Actiniaria, unid.	abundant	tiny white burrowers in silty areas near rock

ANNELIDA-Polychaeta		
Eteone longa	common	
Gattyana cirrosa	uncommon	
Maldanidae, unid	common	
Nephtys nr. _caeca_	abundant	very large
Nephtys nr. _ciliata_	common	
Owenia collaris	common	
Polydora, sp. A.	uncommon	
Pseudomalacoceros sp.	uncommon	
ECHIURA		
Echiurus echiurus alaskanus	abundant	
ARTHROPODA-Crustacea		
Gammaridea #4	uncommon	near rocks
MOLLUSCA		
Clinocardium sp.	common	
Macoma balthica	uncommon	
Macoma lama	uncommon	
Musculus ? _niger_		
Mya truncata	uncommon	
Notoacmaea ?_scutum_		on isolated cobbles
Orobitella ? _rugifera_	common	in _Echiurus_ barrows
Panomya ? _ampla_	uncommon	lowest mud
UROCHORDATA		
Aplidium sp.	uncommon	drifted on beach
CHORDATA-Pisces		
Ammodytes hexapterus	common	

APPENDIX B-6

Iniskin Bay 6/13/76 Tide: -5.2 feet at 0904

Location: Fossil Beach off mouth of Keystone Creek

Near MSL	Rock Bench	
ALGAE-Chlorophyta		
?*Monostroma* sp.		
ALGAE-Phaeophyta		
Fucus distichus	abundant	about 25% cover
Scytosiphon lomentaria	uncommon	
ALGAE-Rhodophyta		
Porphyra sp.		
Rhodomela larix		
CNIDARIA		
Anthopleura ? *xanthogrammica*	uncommon	under rocks
NEMERTEA, unid	uncommon	small, white
ANNELIDA-Polychaeta		
Eteone nr. *longa*	common	in silty areas under rock
Eteone tuberculata	common	in silty areas under rock
Nerine foliosa	uncommon	under rock
ARTHROPODA-Crustacea		
Anisogammarus ? *confervicolus*	abundant	under rock
Balanus cariosus	uncommon	under rock
B. glandula	abundant	about 50% cover
Pagurus hirsutiusculus	common	under rock

MOLLUSCA		
Acmaeidae #2	common	
Buccinum baeri	uncommon	under rock
Liomesus sp.	uncommon	
Littorina sitkana	common	laying eggs in silty pockets
Macoma balthica	common	
Mya ?*arenaria*	abundant	under rock and in silty pockets
Mytilus edulis	common	small individual
Nucella emarginata	common	also many eggs
CHORDATA-Pisces		
Pholis laeta	common	under rocks
Near MLLW to -4 feet	Mud	
ALGAE-Phaeophyta		
Laminaria groenlandica	common	
L. saccharina	abundant	in low channels, many juveniles
ALGAE-Rhodophyta		
Porphyra sp.		
Rhodophyta, unid	abundant	filamentous, in low channels
Rhodymenia palmata	abundant	in low channels
ANGIOSPERMAE		
Zostera marina	common	many small patches
PORIFERA		
Suberites ficus	common	large specimens

CNIDARIA		
Anthopleura artemisia	common	
Metridium senile	uncommon	on low boulders
Obelia longissima	common	on laminarians
Tealia crassicornis	common	on rock in low channel
NEMERTEA, unid	uncommon	small, pink
ANNELIDA-Polychaeta		
Abarenicola pacifica	common	
?*Hesperonoe* sp.	common	in *Echiurus* burrows
Laonome sp. A.	common	
Nephtys nr. *caeca*	common	
Nephtys nr. *cilata*	common	
Pholoe minuta	uncommon	
Maldanidae #2	abundant	to 50/0.0625 m^2
Sabellidae, unid	uncommon	fragment
PRIAPULA		
Priapulus caudata	uncommon	
ECHIURA		
Echiurus echiurus alaskanus	common	
ARTHROPODA-Crustacea		
Balanus crenatus	common	on low pebbles
Crangon alaskensis	common	
Pagurus beringanus	uncommon	
P. kennerlyi		
Telmessus cheiragonus	common	in low channels
MOLLUSCA		
Macoma balthica	common	
Macoma obliqua	common	

Mya ? _arenaria_	common	
Mya truncata	abundant	
Neptunea lirata	uncommon	burrowing in low mud
Orobitella ? _rugifera_		
Psephidia ? _lordi_	common	among eelgrass
BRYOZOA		
Alcyonidium ? _pedunculatum_	common	finely divided and crenulate
Hippothoa hyalina	common	on _Laminaria_ blades
ECHINODERMATA		
Leptasterias polaris acervata	common	in low channels feeding on _Mya_ spp and _Macoma balthica_
CHORDATA-Pisces		
Lepidopsetta ? _bilineata_	common	rock sole; among algae in channels

About -2 feet to -5 feet	_Rock reef; silty_	
ALGAE-Chlorophyta		
?_Monostroma_ sp.	common	
Spongomorpha sp.	abundant	on upper reef
ALGAE-Phaeophyta		
Alaria sp.	uncommon	
Laminaria saccharina	abundant	dominant on lower reef; in channels on reef
Pylaiella littoralis	uncommon	
ALGAE-Rhodophyta		
encrusting coralline algae	uncommon	small patches
Halosaccion glandiforme	uncommon	
Iridaea lineare	common	on low reef

Porphyra sp.	abundant	
Pterosiphonia sp.	common	on lower reef
Rhodymenia palmata	abundant	on upper reef
PORIFERA		
Halichondria panicea		
Haliclona permollis		
Saberites ficus	common	
CNIDARIA		
Abietinaria annulata	uncommon	immature
Actiniaria, unid #1	abundant	tiny, white burrower under rocks and in silt
Actiniaria, unid #3	uncommon	red, many tentacles
Anthopleura ? xanthogrammica		
Cribrinopsis similis	common	large, yellow
Obelia longissima	common	on seaweeds
Tealia crassicornis	common	
ANNELIDA-Polychaeta		
Amphitrite cirrata	common	under rock
Autolytus prismaticus	uncommon	under rock
Cirratulus cirratus cirratus	common	in silty pockets
Glycinde picta	common	under rock
Harmothoe imbricata	common	under rock
Nephtys nr. caeca	common	under rock
Nereis elagica	uncommon	
Nicomache personata	uncommon	
Spirorbis ? medius	common	under rock
Spirorbis ? spirillum	common	on Balanus and under rock

ARTHROPODA-Crustacea

Ampithoe sp.	uncommon	under rock
Balanus balanus	uncommon	
Balanus crenatus	uncommon	
B. glandula	uncommon	
B. rostratus	common	
Crangon alaskensis	uncommon	under rock
Hapalogaster mertensii	common	under rock
Heptacarpus stimpsoni	common	ovigerous
Idothea ? ochotensis	common	under rock
Maera ? loveni	common	under rock
Melita dentata	common	under rock
Oregonia gracilis	common	under rock and among algae
Pagurus beringanus	common	under rock
Pagurus hirsutiusculus	uncommon	under rock
Pagurus ochotensis		
Telmessus cheiragonus	abundant	under rock and in channels

MOLLUSCA-Polyplacophora

?Amicula sp.	common	under rock
Cyanoplax dentiens	common	under rock
Mopalia ciliata	common	under rock

MOLLUSCA-Pelecypoda

Hiatella arctica	common	under rock
Macoma obliqua	common	in silty pockets
Mya ? arenaria	uncommon	in silty pockets
M. truncata	common	in silty pockets

MOLLUSCA-Gastropoda

Buccinum glaciale	uncommon	
Neptunea lirata	uncommon	
Nucella emarginata	common	
Trichotropis insignis	uncommon	

BRYOZOA

Alcyonidium polyoum	common	under rocks
Hippothoa hyalina	common	
Microporella ? californica	uncommon	
?Pachyegis princeps	common	tan and red colonies on barnacles attached to sides and bottoms of rocks
Tegella robertsonae	common	on B. roastratus and Trichotropis
Terminoflustra membranaceo-truncata	common	under and on sides of rocks

ECHINODERMATA

Chiridota sp	common	under rocks
Leptasterias hexactis	common	under rocks
L. polaris acervata	common	two forms, on sides of rocks and in channels
Asterozoa, unid	uncommon	juveniles, just settled

CHORDATA-Pisces

Anoplarchus purpurescens	uncommon	under rock
Lepidopsetta ? bilineata	common	in channels among algae
Pholis laeta	uncommon	under rock

APPENDIX B-7

Iniskin Bay 6/12/76 Tide: -5.3 feet at 0830

Location: "Rocky Point", immediately north of Blackie Cove.

Near MSL	Steep Rock	
ALGAE-Phaeophyta		
Fucus distichus	abundant	
ALGAE-Rhodophyta		
Porphyra sp.	common	
MOLLUSCA		
Littorina sitkana	abundant	
ARTHROPODA-Crustacea		
Balanus glandula	abundant	
MSL to MLLW[1]	Rock bench	
ALGAE-Chlorophyta		
Enteromorpha intestinalis	abundant	
?*Monostroma* sp.	common	
Spongomorpha sp.	abundant	
ALGAE-Phaeophyta		
Alaria sp.	common	
Fucus distichus	uncommon	
Analipus japonicus		
Laminaria groenlandica	common	
L. saccharina	common	
Pylaiella littoralis	common	in pools
Soranthera ulvoides		

[1] Species listed above also common

ALGAE-Rhodophyta		
Callophyllis sp.	abundant	
Gloiopelta furcata		
Iridaea lineare	abundant	
Polysiphonia sp.	common	
Rhodomela larix		
Rhodophyta, unid	abundant	fleshy
Rhodymenia palmata	abundant	
PORIFERA		
Halichondria panicea	common	large patches
Haliclona permollis	abundant	large patches
NEMERTEA		
Paranemertes peregrina	common	among barnacles
ARTHROPODA-Crustacea		
Balanus glandula	abundant	nearly new settlement; empty adult shells common
Telmessus cheiragonus	common	under rocks
MOLLUSCA		
Acmaeidae, unid	common	on sides of large boulders
Littorina sitkana	abundant	
Mytilus edulis	common	many empty shells
Nucella emarginata	common	
BRYOZOA		
Cheilostomata, unid	common	circular orange-brown encrusting colonies under rocks

ECHINODERMATA-Asterozoa

Leptasterias hexactis	common	under rocks

CHORDATA-Pisces

Pholis laeta	common	under rocks

MLLW to -4 feet — Rock and boulder bench

ALGAE-Same as above, except Laminaria groenlandica was the dominant species; many juvenile specimens were also observed.

encrusting coralline algae	common	in pools

PORIFERA

Haliclona permollis	abundant	on sides of rocks
Hymendectyon lyoni		on sides of rocks
?Microciona sp.	uncommon	on sides of rocks
Mycale lingua		
Myxilla incrustans		
Suberites ficus	common	hermit crab shelters; under rocks
Zygherphe hyaloderma		lower rocks

CNIDARIA

Actiniaria, unid #2	common	tiny, white burrower under rocks
Cribrinopsis similis	common	large yellow; on sides of rocks with Tealia
Metridium senile	uncommon	
Tealia crassicornis	common	

ANNELIDA-Polychaeta

Amphitrite cirrata	uncommon	under rock
Brada ? inhabilis	common	
Cirratulus cirratus		
Chone gracilis	common	

Eteone sp. A.	uncommon	
Flabelligera infundibulis	common	
Harmothoe imbricata	common	
Idanthyrsus armatus	uncommon	tube cn _Alcyonidium pedunculatum_
Lepidonotus robustus	uncommon	
Maldanidae, unid	common	
Nephtys nr. _caeca_	common	in silt under rocks
Nephtys nr. _ciliata_	uncommon	in sandy silt pockets
Nereis procera	uncommon	
Nereis vexillosa	common	under rock
Owenia collaris		
Sabella crassicornis	common	under rocks
Spirorbis spp.	common	under rocks
ARTHROPODA-Crustacea		
Ampithoe sp. A	common	
Anisogammarus ?confervicolus	common	under rocks
Anisogammarus sp. A		
Balanus cariosus	uncommon	lower rocks
B. crenatus	abundant	under rocks
B. glandula	common	
_B._ ? _rostratus_	common	
Balanus sp.	uncommon	
Cumella sp.		
Hapalogaster mertensii	common	under rocks

Heptacarpus kincaidi	uncommon	under rock
H. stimpsoni	common	ovigerous
Idothea ochotensis		
Maera ? loveni	common	
Oregonia gracilis	common	under rocks
Pagurus beringanus	common	under rocks
P. kennerlyi	common	under rocks
P. ochotensis	common	under rocks
Paralithodes kamtschatica	common	juveniles, under rocks
MOLLUSCA-Polyplacophora		
Lepidochitona ? internexus		
Mopalia ciliata		
Tonicella lineata		
MOLLUSCA-Pelecypoda		
Clinocardium nuttalli	common	shell only
Hiatella arctica	common	under rocks
Macoma sp.	common	in sand patches
Mya truncata	common	in sand patches
Mytilus edulis	uncommon	
MOLLUSCA-Gastropoda		
Collisella ? pelta	common	on rock
Margarites helicinus	common	under rock
Natica sp.		egg cases only
Neptunea lirata	uncommon	deeper pools
Notoacmea ? scutum	common	under rock
Nucella ? emarginata	uncommon	
Onchidoris bilamellata	common	under rock

BRYOZOA

Alcyonidium pedunculatum	common	on holdfasts of laminarians
A. polyoum	commom	on barnacles and under rocks
Carbasea ? carbasea	common	under rocks
Caulibugula sp.	common	lower rocks
Cheilostomata, unid	common	orange-brown encruster under rocks
Terminoflustra membranaceo-truncata	common	under low rocks and on *Oregonia*

ECHINODERMATA

Chiridota sp.	common	under rocks
Henricia sanguinolenta	common	
H. tumida	uncommon	deeper pools
Leptasterias hexactis	abundant	under rocks on boulders and gravel
L. polaris acervata		several forms; brooding eggs

UROCHORDATA

Aplidium sp.	common	on low boulders
?*Distaplia occidentalis*	common	on low boulders

CHORDATA-Pisces

Anoplarchus purpurescens	uncommon	under rock
Artedius fenestralis	uncommon	under rock
Pholis laeta	common	under rock
Hexagrammos decagrammus	uncommon	in pools - juveniles

APPENDIX B-7a

Iniskin Bay	8/24/76	Tide: +0.4 ft
Time: ∿0800	Depth: Intertidal	Location: Rocky Point

ALGAE-Chlorophyta		
Monostroma sp.	scattered	on rock
Spongomorpha sp.	abundant	on boulders and rocks
ALGAE-Phaeophyta		
Alaria marginata	scattered	on rock and sand
Fucus distichus	abundant	on boulders and rocks
Laminaria groenlandica	scattered	on rock and gravel
L. saccharina	scattered	on rock and gravel
ALGAE-Rhodophyta		
Callophyllis sp.	abundant	on boulders and rocks
Porphyra sp.	abundant	on boulders and rocks
Rhodoglossum affine	scattered	on rock
Rhodymenia palmata	abundant	on boulders and rocks
PORIFERA		
Halichondria panicea	common	
MOLLUSCA-Pelecypoda		
Mya sp.		
ECHINODERMATA		
Leptasterias polaris var. *acervata*	common	

APPENDIX B-8

Iniskin Bay	8/24/76	Time: about 0930
Location: Scott Island		Depth: Intertidal

ALGAE-Chlorophyta

?*Monostroma* sp.	scattered	on rock
Spongomorpha sp.	abundant	on boulders and rocks

ALGAE-Phaeophyta

Alaria marginata	scattered	on rock and sand
Fucus distichus	abundant	on boulders and rocks
Laminaria groenlandica	scattered	on rock and gravel
L. saccharina	scattered	on rock and gravel
Soranthera ulvoides	abundant	on rock and epiphetic on algae

ALGAE-Rhodophyta

Callophyllis sp.	abundant	on boulders and rocks
Halosaccion glandiforme	abundant	on boulders and rocks
Odonthalia sp.	abundant	on rock
Porphyra sp.	abundant	on boulders and rocks
Rhodoglossum affine	scattered	on rock
Rhodymenia palmata	abundant	on boulders and rocks

ARTHROPODA-Crustacea

Balanus sp.

APPENDIX B-9

Chinitna Bay	6/9 and 6/10/76	Tide: +1.9 feet at 1758 and +1.3 feet at 1852

Location: Glacier Spit; off W. Byers site

Above MSL	Rock Cliff	
MOLLUSCA		
Littorina sitkana	abundant	
Mytilus edulis	common	
ARTHROPODA-Crustacea		
Balanus glandula	abundant	
Chthamalus dalli	common	
About +2 feet	Rock Outcrop	
CNIDARIA		
Anthopleura ? *xanthogrammica*	common	in moist crevices
ANNELIDA-Polychaeta		
Eteone nr. *longa*	abundant	spawning among barnacles
MOLLUSCA		
Acmaeidae, unid	common	
Littornia sitkana	uncommon	
Mytilus edulis	uncommon	
Nucella emarginata	common	
ARTHROPODA-Crustacea		
Balanus glandula	abundant	

About +2 feet -3 feet[1]	Mud Flat	
ALGAE-Phaeophyta		
Laminaria saccharina	sparse	
Pylaiella littoralis	abundant	
ALGAE-Rhodophyta		
Porphyra sp.		
CNIDARIA		
Anthopleura artemesia	common	at lower levels
ANNELIOA-Polychaeta		
Abarenicola pacifica	common	
?Hesperonoe sp.	common	scaleworm in Echiurus burrows
Nephtys nr. caeca	abundant	
Sabellidae, unid	uncommon	fragment only
ECHIURA		
Echiurus echiurus alaskanus	abundant	
MOLLUSCA-Pelecypoda		
Clinocardium nuttalli	abundant	some very large
Macoma balthica	abundant	burrowing from surface to 5 cm. deep
Mya ? arenaria	abundant	densities to near 50/0.25
Orobitella ? rugifera	common	in Echiurus burrows and attached to host

[1] Species present above MSL also present here on scattered cobbles

APPENDIX B-10

Chinitna Bay 6/11/76 Tide: -4.7 feet at 0734

Location: Clam Beach 0.1 mile East of E. Glacier Creek

MLLW to -4 feet	Clean sand	
ANNELIDA-Polychaeta		
Capitella capitata	uncommon	
Eteone nr. *longa*	common	
Nephtys nr. *caeca*	common	
Nephtys nr. *parva*	common	
Scolelepis sp.	common	
MOLLUSCA		
Siliqua patula	abundant	well over 1 adult/m^2 many age 0 and 1
ARTHROPODA-Crustacea		
Crangon alaskensis	uncommon	low wet sand
Eohaustorius spp.	common	
?*Neomysis* sp.	common	females carrying young
Orchestia georgina		
Orchestia sp.		
CHORDATA-Aves		
Charadrius semipalmatus	common	
Larus spp.	common	
Ixoreus naevius	uncommon	on upper beach

APPENDIX B-11

Location: Gull Island 6/10/76

Above MSL	Bedrock Cliff	
LICHENS		
?Caloplaca sp.	common	
?Verrucaria sp.	common	
ALGAE-Chlorophyta		
Prasiola meridionalis	common	
Between MSL and MLLW	Bedrock and Boulders	
ALGAE-Chlorophyta		
Chlorophyta, unid	common	filamentous
?Monostroma sp.	common	
ALGAE-Phaeophyta		
Alaria sp.	uncommon	in pools
Fucus distichus	common	
?Ilea sp	common	in channels
Pylaiella littoralis	common	in pools
Scytosiphon lomentaria	common	in pools
ALGAE-Rhodophyta		
encrusting coralline algae	uncommon	in pools
?Endocladia sp.	common	
Halosaccion glandiforme	abundant	
Rhodomela larix	common	in pools
Rhodophyta, unid	common	filamentous

Rhodophyta, unid	common	like _Gracilaria_
Rhodymenia palmata	common	in pools
PORIFERA		
Halichondria panicea	common	in pools
CNIDARIA		
Telia crassicornis	uncommon	in pools
ARTHROPODA-Crustacea		
Balanus glandula	abundant	
Chthamalus dalli	common	
Pagurus sp.	common	tiny, in pools
MOLLUSCA		
Littorina sitkana	common	
Mytilus edulis	common	
Nucella emarginata	common	
CHORDATA-Aves		
Actitis macularia	uncommon	spotted sand piper
Fratercula corniculata	common	Horned puffin; nesting
Haematopus bachmani	uncommon	Black oyster catcher
Larus canus	uncommon	Mew gull
L. glaucescens	abundant	Glaucous-winged gull; nesting
Lunda cirrhata	abundant	Tufted puffin; nesting
Somateria mollissima	uncommon	Common eider
Zonotrichia atricapilla	uncommon	Golden-crowned sparrow
CHORDATA-Mammalia		
Phoca vitulina	common	Harbor seal, feeding

Chinitna Bay 6/10/76 Tide: -3.6 feet at 0645

Location: Rocky Point about 0.5 mi west of Spring Point

Near MLLW	Boulders and sand pockets	
ALGAE-Chlorophyta		
Enteromorpha intestinalis	abundant	
?*Monostroma* sp.	abundant	
Ulothrix sp.	abundant	
ALGAE-Phaeophyta		
Alaria sp.	uncommon	
Desmarestia aculeata	common	
Fucus distichus	uncommon	
Laminaria groenlandica	uncommon	
Pylaiella littoralis	common	
Scytosiphon lomentaria	common	
ALGAE-Rhodophyta		
Ahnfeltia plicata	common	
Odonthalia floccosa		
?*Polysiphonia* sp.	common	
Rhodomela larix		
Rhodymenia palmata	common	
PORIFERA		
Halichondria ? *panicea*	common	under sides of boulders
?*Haliclona permollis*		

CNIDARIA		
Anthopleura artemisia	common	in silty sand pockets
Cribrinopsis similis	common	large yellow
ANNELIDA-Polychaeta		
Abarenicola pacifica	common	locally abundant in silty pockets
Eteone nr. *longa*	common	in silty sand
MOLLUSCA		
Collisella ? *pelta*	common	
Mya sp.		
Notoacmea ? *scutum*	common	
Nucella emarginata	abundant	very dense; feeding on barnacles
ARTHROPODA-Crustacea		
Anisogammarus ? *pugettensis*	common	under rocks
Balanus cariosus	common	small
Balanus glandula	abundant	dense new set
Chthamalus dalli	abundant	
Pagurus hirsutiusculus	common	
Paraphoxus obtusidens	common	in clean sand
BRYOZOA		
?*Tricellaria* sp.	common	on sides of rocks
ECHINODERMATA		
Leptasterias hexactis	common	
CHORDATA-Mammalia		
Ursus americanus(black bear)	uncommon	one seen on mid intertidal rocks

MLLW to -5 feet	Rock bench	
ALGAE-Chlorophyta		
Chlorophyta, unid		filamentous
?*Monostroma* sp.	uncommon	
ALGAE-Phaeophyta		
Agarum cribrosum	uncommon	
Alaria sp.	uncommon	
Fucus distichus	uncommon	
Laminaria groenlandica	abundant	
L. saccharina	common	
Ralfsia pacifica	uncommon	
ALGAE-Rhodophyta		
Callophyllis sp.	common	
Ceramium sp.		
Constantinea subulifera	uncommon	
Corallina ? *vancouveriensis*	common	
encrusting coralline algae	common	
Iridaea lineare	common	
Membranoptera weeksiae		
Odonthalia kamschatica		
Pterosiphonia sp.		
Rhodomela larix		
Rhodophyta, unid	common	filamentous
Rhodymenia palmata	common	

PORIFERA		
?*Microciona* sp.	uncommon	on side of rock
CNIDARIA		
Abietinaria filicula	common	complex branching
Actiniaria, unid #1	common	under rock; tiny, white
Anthopleura artemisia	uncommon	in silty pockets
?*Anthopleura* sp.	common	burrowing
Campanulariidae, unid	common	in pools
Cribrinopsis similis	common	large, yellow
Tealia crassicornis	common	in pools
NEMERTEA, unid	uncommon	small, white
ANNELIDA-Polychaeta		
Autolytus sp.	uncommon	
Brada ? *inhabilis*	common	
Eteone nr. *longa*	common	
Harmothoe extenuata		
Maldanidae, unid	common	encrusting sand tubes under rock
Nephtys nr. *caeca*	common	in silty sand and shell pockets
Nephtys nr. *ciliata*	uncommon	
Nereis vexillosa	common	some epitokus
Nereis sp. A.	common	
Nicomache personata	common	encrusting buried rock
Owenia collaris	common	in sand and gravel under cobbles
Phyllodoce sp.	common	
Polynoidae, unid	uncommon	not collected
Sphaerosyllis sp. A.	uncommon	
Spirorbis spp.	common	
Typosyllis sp.	uncommon	

MOLLUSCA

?Amicula sp.	common	
Cyanoplax dentiens	common	under rock
Hiatella arctica	uncommon	shell only
Lepidochitona ? internexus	common	under rock
Macoma obliqua	common	in silty sand and shell pockets
Mopalia ciliata	common	
Mya ? arenaria	common	under cobble
Mya truncata	common	among cobble
Notoacmea ? scutum	common	
Nucella emarginata	uncommon	
Tonicella lineata	common	
Trichotropis insignis	uncommon	

ARTHROPODA-Crustacea

Ampithoe sp.	common	under rock
Anisogammarus sp.	common	under rock
Balanus ? glandula	abundant	spat
Hapalogaster mertensii	common	under rock
Heptacarpus stimpsoni	common	ovigerous
Ischyroceros sp.	common	under rock
Maera ? loveni	uncommon	under rock
Pagurus beringanus	common	
Pagurus hirsutiusculus	common	
Pentidothea sp.	common	under rock
Pontogenia sp.	uncommon	
Telmessus cheiragonus	uncommon	

BRYOZOA		
Alcyonidium polyoum	common	under rocks
Caulibugula sp.	common	
?*Entalophora capitata*	uncommon	under rocks
ECHINODERMATA		
Eupentacta ? *quinquesemita*	uncommon	under rocks
Henricia leviuscula	common	in pools
Leptasterias hexactis	common	under rocks
Ophiopholis aculeata	uncommon	under rocks
Strongylocentrotus drobachiensis	common	under rocks
CHORDATA-Pisces		
Artedius fenestralis	common	breeding
Liparis sp.	uncommon	under rocks

Appendix B-11a. Shell length data: Nucella emarginata, Spring Point; 6/10/76.

Shell length (mm)	Frequency	Shell length (mm)	Frequency
12	1	29	5
13	0	30	14
14	0	31	17
15	0	32	20
16	0	33	14
17	1	34	20
18	1	35	18
19	3	36	11
20	6	37	9
21	5	38	5
22	7	39	5
23	10	40	3
24	4	41	1
25	5	42	2
26	3	43	0
27	4	44	0
28	5	45	1

$n = 201$

$\overline{x} = 30.8$

$s = 5.8$

APPENDIX B-12

Polly Creek Beach 7/13/76 Tide: -3.3 feet at 1020

Location: Outer sand bars off Polly Creek

About -1 to -3 feet	Sand	
CNIDARIA		
Thuiaria cylindrica		drift
ANNELIDA-Polychaeta		
Euzonus nr. *dillonensis*	uncommon	in coarse sand
Nephtys nr. *caeca*	uncommon	in coarse sand
Nephtys nr. *parva*		in coarse sand
Scolelepis sp.	uncommon	partial specimen
MOLLUSCA		
Macoma lama	uncommon	shell only
Siliqua patula	abundant	densities to $6/0.25m^2$
Spisula polynyma	uncommon	small, large shell abundant
ARTHROPODA-Crustacea		
Anisogammarus ? *pugettensis*	uncommon	
Archaeomysis grebnitzkii	common	in finer sand
Eohaustorius spp.	common	in finer sand
Pagurus ochotensis	uncommon	drift
ARTHROPODA-Insecta		
Tricoptera larvae	common	in sand tubes
BRYOZOA		
Alcyonidium enteromorpha	uncommon	on pebble
A. pedunculatum	uncommon	on pebble

APPENDIX C

SUBTIDAL RECONNAISSANCE SITES
IN LOWER COOK INLET

Appendix C-1. Relative abundance of organisms in 12.8 m off Archimandritof Shoals on 8/3/76.

Species	Relative Abundance	Remarks
ALGAE		
Agarum cribrosum	S	
encrusting coralline alga	50% cover	
Hildenbrandia sp.		
Pterosiphonia sp.	D	
Rhodymenia pertusae		
INVERTEBRATA		
Abietinaria variabilis	A	
Acmaea mitra	C	
Aplousobranchia, unid.		
Balanus ? *crenatus*		
B. nubilus		
Beania sp.		
Beringius kennicotti		
Boreotrophon clathratus		
B. ? *plectrum*		
Buccinum glaciale		
Campanularia verticillata		
Calycella syringa		
Crossaster papposus	U	
Cryptobranchia concentrica	A	
Dendrobeania murrayana		
Elassochirus tenuimanus		
?*Eudistylia vancouveri*		
Flustrella gigantea	C	spawning
Fusitriton oregonensis	C	under rocks
Golfingia sp.	C	
Halecium muricatum		
Halecium sp.		
? *Haliclona* sp.	C	
Halocynthia aurantia	C	
Hyas lyratus		
Idanthyrsus sp.		
Lafoea fruticosa		
Leptasterias polaris var. *acervata*	U	
Macoma sp.		
Modiolus modiolus	C	
Mopalia sp.		
Musculus discors		
Mya truncata		
Mysidacea, unid.	A	in bottom water
Natica sp.		
Neptunea lirata	C	spawning
Octopus sp.	U	
Oregonia gracilis	C	
Orothopyxis caliculata		
Owenia collaris		

Appendix C-1 (cont. Relative abundance of organisms in 12.8 m off Archimandritof Shoals on 8/3/76.

Species	Relative	Remarks
Pagurus ?cornutus		
Pandalidae, unid.	U	3 mm carapace length; in Lafoea
Paralithodes kamtschatica		
Placiphorella sp.	C	
Pododesmus macroschisma	C	
Potamilla sp.		
Protothaca staminea		
Psolus ? chitonoides		
Sertularella polyzonias var. gigantea	C	several spp.
Sertularia cupressoides		
S. ?nana		
Strongylocentrotus droebachiensis	A	
S. ? pallidus	C	
Terebratalia transversus		
Terminoflustra membranaceo-truncata	C	
Thelepus cincinnatus		
Tonicella insignis		
T. lineata		
Tricellaria erecta		
Trophonopsis lasius		
CHORDATA-Pisces		
Agonus acipenserinus	U	sturgeon poacher
Hexagrammos stelleri		white spotted greenling
Liparis sp.		snail fish
Pleuronectiformes, unid.		flat fish

Appendix C-1a. Species observed on Archimandritof Shoals in fall 1974 on cobble at 10 m.

ALGAE

Agarum cribrosum

Laminaria groenlandica

Nereocystis luetkeana

CHORDATA-Pisces

Cottidae, unid.

INVERTEBRATA

Chioncetes bairdi

Crossaster papposus

? *Evasterias troschelii*

Halocynthia aurantia

Mya truncata

Pandalidae, unid.

Pododesmus macroschisma

Potamilla sp.

Strongylocentrotus droebachiensis

Appendix C-1b. Species composition, distribution and abundance data for rocky subtidal substrata off Archimandritof Shoals, November 1975.

Taxon	4.9 m (16') 11/05/75	7.6 m (25') 11/06/75	Remarks
ALGAE			
Agarum cribrosum	C	A,D	
? *Cryptonemia* sp.	C	C	
Cymathere triplicata	U	-	
Desmarestia viridis	C	-	on cobble
encrusting coralline alga	O	A	50-75% cover on cobbles & boulders
Laminaria groenlandica	A,D	-	on boulders
Lithothrix sp.	-	C	
PORIFERA			
unid. yellow encrusting sponge (spatter sponge)	-	O	
CNIDARIA			
Cribrinopsis similis	-	O	
Thuiaria spp.	C	C	
ANNELIDA			
Crucigera zygophora	U	C	
?*Eudistylia vancouveri*	-	C	
unid. polychaete, errantiate	-	U	leaving mucus trail on rock surface
Owenia collaris	-	A	
Potamilla sp.	-	A	forming beds
BRACHIOPODA			
? *Diestothyris frontalis*	-	O	
Terebratalia transversa	-	O	
BRYOZOA			
Flustrella gigantea	C	C	
? *Rhynchozoon* sp.	-	O	
MOLLUSCA			
Acmaea mitra	-	C	
Beringius kennicotti	-	O	
Buccinum glaciale	-	U	
Calliostoma ligatum	-	O	
unid. dorid nudibranch (? *Cadlina* sp.)	-	O	white with pale yellow spots
unid. dorid nudibranch	-	O	white with yellow tubercles
egg mass, unid.	S	-	Buccinidae
Fusitriton oregonensis	C	C	

Appendix C-1b(Cont.). Species composition, distribution and abundance data for rocky subtidal substrata off Archimandritof Shoals, November 1975.

Taxon	4.9 m (16') 11/05/75	5.6 m (25') 11/06/75	Remarks
Modiolus modiolus	U	A,D	large individuals; >30/sq.m. on 11/6
Natica ? *clausa*	O	C	large, on rock surface
Neptunea lirata	C	C	
Pododesmus macroschisma	U	C	
Tonicella sp.	O	C	
Trichotropis insignis	-	C	in small cavities in boulders
ARTHROPODA			
Balanus ? *glandula*	A,D	-	most common on boulders
B. nubilus	U	O	
Caridea, unid.	-	A	small species
Chionocetes bairdi	S	-	juveniles
Crangon sp.	-	O	
Elassochirus tenuimanus	-	S	
Hyas lyratus	C	O	
Paguroidea, unid.	C	A	small species
Telmessus cheiragonus	O	-	on sand
ECHINODERMATA			
Crossaster papposus	U	O	
Cucumaria fallax	U	-	on top of boulders
? *Leptasterias polaris* var. *acervata*	C	U	large, 5(?) and 6 rayed
? *Leptasterias hexactis*	C	U	small, 6 rays, under rocks
Ophiopholis aculeata	-	O	
Strongylocentrotus droebachiensis	C	A,D	feeding on *Agarum* on 11/5
UROCHORDATA			
Halocynthia aurantia	-	U	
CHORDATA			
Cottidae, unid.	-	C	small spp.
Pleuronectiformes, unid.	U	-	
Number of species	28	42	

50 spp. observed

C = common
O = observed
A = abundant
U = uncommon
D = dominant

Appendix C-1c. Species composition, distribution and abundance data for rocky subtidal substrate off Archimandritof Shoals, April 1976.

Taxon	4.3 m (14') 4/20/76	6.7 m (22') 4/20/76	6.7 m (22') 4/29/76
ALGAE			
Agarum cribrosum (adults)	P	14.7 ± 9.4 (45.8 ± 23.8)	A,D
Agarum cribrosum (juveniles)	-	6.0 ± 6.0	-
? *Cryptonemia* sp.	-	(9.2 ± 5.8)	-
encrusting coralline alga	(61.9 ± 22.7)	(60.0 ± 14.1)	A
Lithothrix sp.	-	P	-
Halicystis ovalis	-	P	-
Pterosiphonia bipinnata	-	-	C
PORIFERA			
? *Microciona* sp.	P	-	-
CNIDARIA			
Actiniaria, unid., 2 spp.	-	-	P
Thuiaria sp.	1.6 ± 2.0	-	P
ANNELIDA			
Cistenides brevicomis	P	-	-
Crucigera zygophora	-	P	C
?*Eudistylia vancouveri*	-	P	-
Owenia collaris	P	P	-
unid., errantiate polychaete	P	-	-
Potamilla neglecta	-	P	P
BRACHIOPODA			
Hemithyris psittacea	-	P	-
MOLLUSCA			
Acmaea mitra	1.6 ± 2.8	P	-
Buccinum glaciale	P	-	-
Clinocardium nuttalli	P	-	-
Cryptobranchia concentrica	P	P	P
Cryptochiton stelleri	P	P	-
Fusitriton oregonensis	1.2 ± 2.0	2.0 ± 3.2	-
Lacuna sp.	-	P	-
Macoma ? *inquinata*	P	-	P
Margarites sp.	-	1.2 ± 3.2	-
Modiolus modiolus	∿2.0	74.8 ± 57.6	-
Natica ? *pallida*	-	-	-
Neptunea lirata	3.2 ± 5.6	1.2 ± 3.2	P
Opalia sp.	-	P	-
Panomya ampla	-	1.2 ± 2.4	P
Pododesmus macroschisma	2.0 ± 2.0	P	-
Protothaca staminea	P	-	P
Saxidomus gigantea	6.4 ± 5.6	-	A
Tonicella insignis	-	-	P

Appendix C-1c(Cont.). Species composition, distribution and abundance data for subtidal substrate off Archimandritof Shoals, April 1976.

Taxon	4.3 m (14') 4/20/76	6.7 m (22') 4/20/76	6.7 m (22') 4/29/76
Tonicella sp.	P	8.8 ± 6.8	-
Trichotropis insignis	1.2 ± 2.0	P	-
Trophon multicostatus	-	P	-
Volutharpa ampullacea	P	-	-
ARTHROPODA			
Balanus nubilus	-	P	P
Cragonidae, unid.	P	-	-
Elassochirus gilli	-	P	-
Gammaridea, unid.	-	-	abundant in water column
Hyas lyratus	P	-	-
Paguridae, unid.	P	-	P
Pandalidae, unid.	-	P	-
CHAETOGNATHA	abundant in water column	-	-
ECHINODERMATA			
Crossaster papposus	-	0.04	-
Cucumaria miniata	P	-	P
Leptasterias polaris var. *acervata*	P	P	P
Ophiopholis aculeata	-	-	P
Pteraster tesselatus	-	0.04	-
Strongylocentrotus droebachiensis	83.2 ± 38.0	22.0 ± 10.0	-
S. ? *pallidus*	6.0 ± 9.2	P	-
TUNICATA			
Halocynthia aurantia	-	-	P
CHORDATA-PISCES			
Cottidae, unid.	P	-	P
Pholidadae	P	-	-
Number of species	32	32	23

56 species observed

A = abundant
P = present
C = common
D = dominant

Appendix C-1d. Size data for Strongylocentrotus spp. off the Salty Dawg Saloon, Archimandritof Shoals, in 10 m on 8/3/76. Some females developing gonads.

Test Diameter (mm)	Frequency	Test Diameter (mm)	Frequency
16	1	37	3
20	1	38	3
21	3	39	3
22	1	40	6
23	2	41	3
24	1	42	4
25	1	43	6
26	1	44	4
27	2	45	9
28	1	46	6
29	1	47	8
30	1	48	5
32	4	49	2
33	2	50	1
34	1	51	2
35	2	52	4
		56	1

$n = 95$

$\bar{x} \pm s = 40.0 \pm 8.9$ mm

Appendix C-1e. Size data for *Modiolus modiolus* off Salty Dawg Saloon, Archimandritof Shoals, in 11 m on 8/3/76.

Shell Length (mm)	Frequency	Shell Length (mm)	Frequency
19	1	71	2
26	1	72	1
32	1	73	1
39	1	74	1
41	1	77	2
43	1	78	1
44	1	79	2
50	1	81	2
52	1	95	3
55	2	100	1
58	2	104	1
61	1	111	1
64	1	114	1
65	1	117	1
67	1	121	1
69	2	127	1
70	2		

$n = 43$

$\bar{x} \pm s = 72.1 \pm 25.3$ mm

Appendix C-1f. Size data for Fusitriton oregonensis from off the Salty Dawg Saloon in 10 m on 8/3/76.

Aperture Length (mm)	Frequency
18	1
28	1
31	2
32	1
33	2
34	1
38	1
39	1
40	1
41	2
43	1
44	1
45	3
48	1
50	2
51	2
52	1
56	1
60	1

$n = 26$

$\bar{x} \pm s = 41.5 \pm 9.7$ mm

Appendix C-1g. Feeding observations at Archimandritof Shoals in November 1975, April and August 1976.

Predator Species	Type of Observations	Number	Prey Species
Crossaster papposus	Direct	1	Hydroid and chiton
	Direct	1	*Strongylocentrotus* sp. (juv.)
Leptasterias polaris var. *acervata*	Direct	Several	*Balanus glandula*
		1	unid. clam
		1	*Protothaca staminea*
Natica clausa	Indirect	Numerous	*Macoma* sp.
Strongylocentrotus droebachiensis	Direct	Numerous	*Agarum cribrosum*
Leptasterias polaris var. *acervata*	Direct	2	*Modiolus modiolus*
	Direct	1	*Clinocardium caliiforniense*
Pteraster tesselatus	Direct	1	*Abietinaria* sp.

Appendix C-2. Species observed in 14.6 m off Seafair Beach on 8/3/76.

ALGAE

encrusting coralline alga

?*Opuntiella* sp.

Rhodymenia palmata

R. pertusae

CHORDATA-Pisces

Agonidae, unid.

Pleuronectiformes, unid.

Ronquilus jordani

INVERTEBRATA

Abietinaria spp.

Acmaea mitra

Balanus nubilus

Buccinum glaciale

Clinocardium californiense

Dendrobeania murrayana

Elassochirus tenuimanus

Flustrella gigantea

Fusitriton oregonensis

Halecium ? *muricatum*

? *Haliclona* sp.

Halocynthia aurantia

Leptasterias polaris var. *acervata*

Modiolus modiolus

Mysidacea, unid.

Ophiopholis aculeata

Oregonia gracilis

Pagurus ?*confragosus*

Placiphorella sp.

Pododesmus macroschisma

Pteraster tesselatus

Serripes groenlandicus

Suberites ficus

Tonicella insignis

Tresus capax

Appendix C-2a. Size data for <u>Strongylocentrotus</u> spp. in 14.6 m about 1 mi. off Seafair Beach, Homer, on 8/3/76.

Test Diameter (mm)	Frequency
28	1
44	1
45	1
46	2
47	2
48	2
49	3
50	6
52	3
53	2
54	4
55	4
56	5
57	2
59	1
60	1

$n = 40$

$\bar{x} \pm s = 51.4 \pm 5.5$ mm

Appendix C-2b. Size data for *Modiolus modiolus* in 14.6 m about 1 mi. off Seafair Beach, Homer, on 8/3/76.

Shell Length (mm)	Frequency	Shell Length (mm)	Frequency
35	1	103	2
75	1	105	3
83	1	106	3
89	1	108	1
94	1	109	1
96	1	112	3
99	3	114	3
101	1	118	1
102	1	121	2

$n = 30$

$\bar{x} \pm s = 102.2 \pm 16.3$ mm

Appendix C-2c. Size data for two gastropods in 14.6 m about 1 mi. off Seafair Beach, Homer, on 8/3/76.

Aperture lengths (mm) for *Fusitriton oregonensis*:

36, 52, 53, 54
$\bar{x} \pm s = 48.8 \pm 8.5$ mm

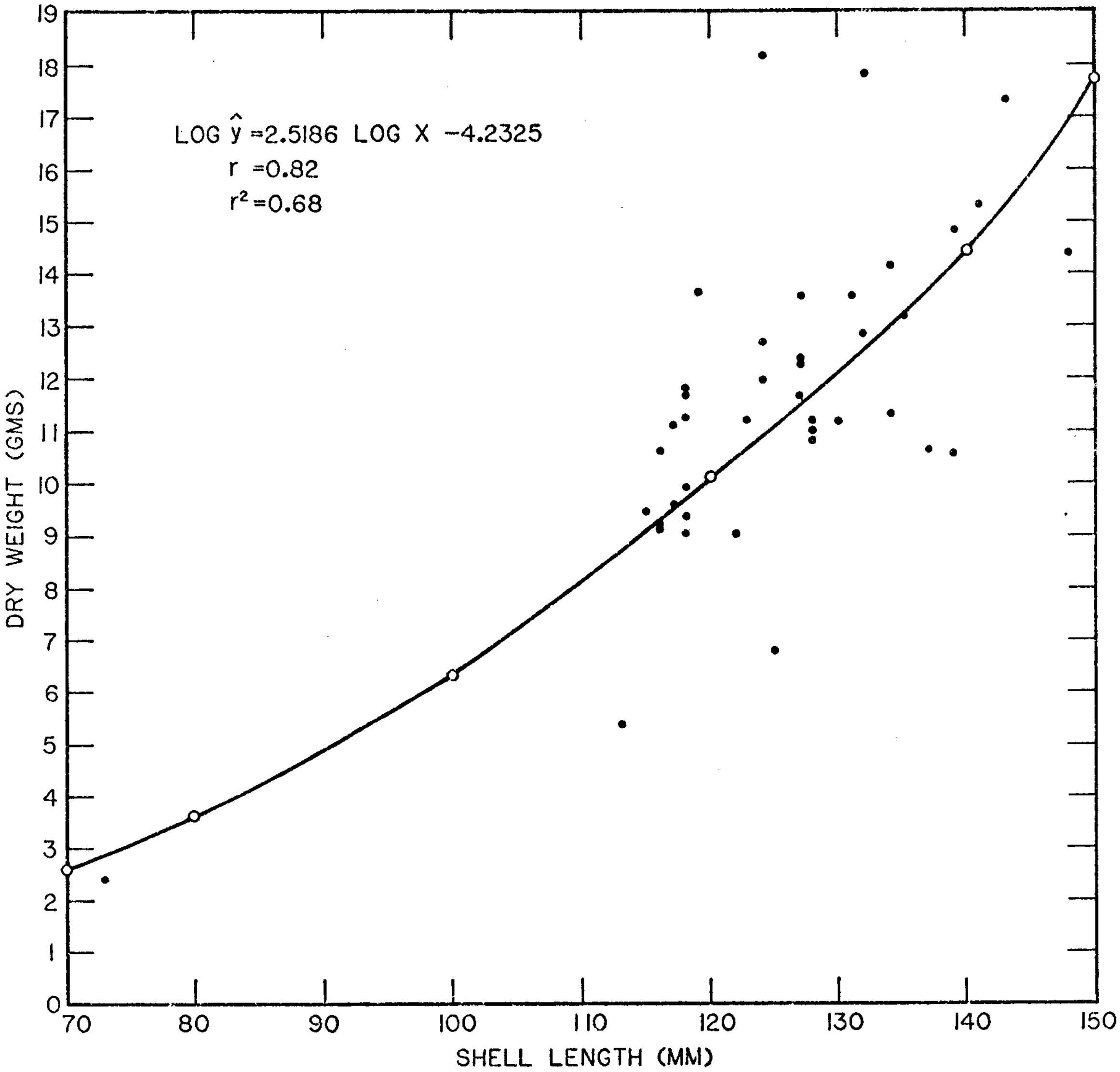
Aperture lengths (mm) for *Neptunea lirata*:

28, 30, 31, 31, 34, 36, 37, 38, 39, 43
$\bar{x} \pm s = 35.1 \pm 4.7$ mm

Appendix C-3. Shell length-weight data; Modiolus modiolus from a depth of 11.9 m off Bluff Point, 10/25/75 (yield from about 1 sq.m. of substrate).

Shell Length (mm)	Wet Tissue Weight (gms)	Dry Tissue Weight (gms)	Percent Loss
73	18.60	2.45	86.8
108	63.01	8.28	86.9
113	63.83	5.41	91.5
115	64.00	9.46	85.2
116	46.21	10.58	77.1
116	54.84*	9.17	83.3
116	59.22	9.22	84.4
117	46.15	8.11	82.4
117	56.07	9.56	82.9
117	81.38	11.06	86.4
118	110.00*	11.27	89.8
118	77.87	11.72	84.9
118	83.20	11.81	85.8
118	55.87	9.02	83.9
118	47.33	9.34	80.3
118	80.68	9.90	87.7
119	60.90	13.59	77.7
120	78.57*	10.01	87.3
122	55.77	9.03	83.8
123	85.43	11.14	87.0
124	92.82*	11.96	87.1
124	66.76	12.64	81.1
124	98.41	18.13	81.6
125	44.93**	6.78	84.9
127	107.40	13.51	87.4
127	79.17*	12.24	84.5
127	69.91*	11.62	83.4
127	78.90	12.30	84.4
128	62.49	10.99	82.4
128	76.36*	12.25	84.0
128	77.11*	11.15	85.5
128	81.60*	10.81	86.8
130	102.84	11.13	89.2
131	85.15*	13.52	84.1
132	83.54	17.84	78.6
132	75.58*	12.81	83.1
134	88.81	14.07	84.2
134	103.34	11.34	89.0
135	82.36	13.21	84.0
137	64.40**	10.58	83.6
139	81.98*	14.79	82.0
139	69.43*	10.51	84.9
141	115.03*	15.30	86.7
143	100.54	17.29	82.8
148	107.42*	14.37	86.6
Total 45	3,385.21	511.26	$\bar{x} \pm s = 84.6 \pm 3.0\%$

* Mature female
** Male



APPENDIX C-3a

RELATIONSHIP BETWEEN SHELL LENGTH AND DRY TISSUE WEIGHT FOR MODIOLUS MODIOLUS FROM BLUFF POINT

DAMES & MOORE

Appendix C-4. Abundance and relative cover of organisms off Anchor Point-Troublesome Creek in summer 1976

Tax A		Station 1	Station 2	Station 3	Station 4	Station 5
	Depth	20 m	14 m	14.6 m	11 m	12.8 m
	Date	7/20	7/20	7/22	7/22	8/3
ALGAE-Chlorophyta						
Codium ritteri					P*	
ALGAE-Phaeophyta						
Agarum cribrosum			U		P	D
Desmarestia ligulata			33.3±20.8%	P	P	D
D. viridis			6.7± 5.8%		P	P
Laminaria groenlandica (juv.)		U				
L. groenlandica (adult)			1.2; 10.3±17.3%**		P	P
Laminaria sp.			1.7; 0.7%			
ALGAE-Rhodophyta						
Constantinea sp.					P	
encrusting coralline alga		U	6.7± 7.6%	40.0±21.6%		D
?Opuntiella sp.		U		45.0±22.7%		P
Rhodophyta, unid. (filamentous)				0.7%		
Rhodymenia pertusae		U				
PORIFERA						
Esperiopsis ? laxa						U
E. quatsinoensis						A
Esperiopsis sp.		P				
?Esperiopsis sp. (funnel-shaped)		P				
Halichondria ?panicea						D
Mycale ?lingua						A
Porifera, unid						P
?Scypha sp						
CNIDARIA						
Abietinaria turgida		P	8.3± 7.6%	1.8± 2.4%		A
A. variabilis				G		A
Actiniaria, unid (fuchsia)						U
Campanularia verticillata		P		P		
Cribrinopsis similis					P	C
Eudendrium vaginatum			15.0± 5.0%	G		
Gersemia rubriformis						
Halecium marsupiale					C	
H. speciosum						U
Hydroida, unid		A				
Lafoea dumosa				G,C		C
Metridium senile						C
Sertularella albida				C		C,G
S. polyzonias var. gigantea				C		C
S. tenella				P		
S. tricuspidata				C		C
Sertularia cuspressina				U		
S. cupressoides				C		A
S. tenera				P		
Tealia crassicornis			0.5			C
ANNELIDA-Polychaeta						
Ampharetidae, unid						P
Nereis mediator						P
Nereis sp. (juv.)						
MOLLUSCA-Pelecypoda						
Entodesma saxicola		P	1.2			
Hiatella arctica		P				
Humilaria ennerlyi		P				
Macoma sp.		P				
Modiolus modiolus		P		12.6		
Mya sp.						P
Saxidomus giganteus		P	P	3.2		A
Tresus capax						C

Appendix C-4. (cont.) Abundance and relative cover of organisms off Anchor Point-Troublesome Creek in summer 1976

	Station 1	Station 2	Station 3	Station 4	Station 5
Depth	20 m	14 m	14.6 m	11 m	12.8 m
Date	7/20	7/20	7/22	7/22	8/3
MOLLUSCA-Gastropoda					
Acmaea mitra		1.2			P
Aeolidida unid.					U
Buccinum glaciale					C
Cryptobranchia sp.		P	P		P
Dendronotus sp.					P
Fusitriton oregonensis		S			C,S
Hermissenda crassicornis					C
Margarites pupillus			P		P
Neptunea lyrata		1.2, 5			C,S
Trichotropis cancellata					A,S
Triopha carpenteri	S				
Trophonopsius lasius					P
Velutina sp. (white foot, orange margin)					P
Volutopsius sp.					P
MOLLUSCA-Polyplacophora					
Cryptochiton stelleri	P	0.9	P		P
Ischnochiton sp.			P		
Mopalia sp.			3 spp.		P
Tonicella insignis					P
T. lineata			P		P
Tonicella sp.		5.2	3.2		
ARTHROPODA-Crustacea					
Balanus nubilus		2.4	1.2		C
Cancer oregonensis	P		P		P
Elassochirus gilli	P				P
E. tenuimanus					C
Hippolytidae, unid.		P			
Hyas lyratus	P				
Oregonia gracilis	P				P
Pagurus ennerlyi					P
P. ochotensis	P				
Paguridae, unid.	P	P			
Placetron wosnesenskii	P				
Pugettia gracilis		P	P		
Sclerocrangon sp.	P				
Scyra acutifrons		C,G			
BRYOZOA					
Alcyonidium pedunculatum	P				
Bryozoa, unid	C				
Cauloramphus sp.			P		
Flustrella gigantea	C	6.7± 7.6%		P	A
Heteropora sp.		2.0± 2.0%			U
Microporina borealis					P
?Rhynchozoon sp.					P
Scruparia ambigua			P		
ECHINODERMATA					
Crossaster papposus	0.025			P	U
Cucumaria fallax	1.2	1.2			C
Cucumaria miniata	10.6	14.6		P	C
Dermasterias imbricata	0.025	P			C
Evasterias troschelii	0.025	P			C
Henricia leviscula					P
H. Sanguinolenta	0.425	P	P		P
H. tumida	P				
Ophiopholis aculeata		P	P		P
Orthasterias koehleri		P			

Appendix C-4 (cont.) Abundance and relative cover of organisms off Anchor Point-Troublesome Creek in summer 1976

	Station 1	Station 2	Station 3	Station 4	Station 5
Depth	20 m	14 m	14.6 m	11 m	12.8 m
Date	7/20	7/20	7/22	7/22	8.3
ECHINODERMATA					
Pteraster tesselatus	P	P			
Pyncopodia helianthoides		P			
Solaster dawsoni		P		P	
S. stimpsoni		P			P
Strongylocentrotus droebachiensis		P	3.2	P	A
S. ?pallidus	3.8	37.9	2.0		A
URCHORDATA					
?Aplidium sp. (golden)					C
Ritterella pulchra		3.3 +2.9%			P
Stylae clava		P			P
CHORDATA-Pisces					
Cottidae, unid	P				P
Hemilepidotus sp.		P		P	C
Hexagrammos decagrammus		P		P	C
H. lagocephalus		P			C
H. stelleri		P	P		C
Myoxocephalus ? polyacanthocephalus					C
Pholis laeta					P
Ronguilus jordani	P	P		P	P

Footnotes:

* A - abundant
C - common
D - dominant
P - present
U - uncommon
S - spawning; implies presence
G - gravid

** Unspecified numers indicate estimated number of organisms per m^2

Appendix C-4a. Size data for *Strongylocentrotus* spp. in 20 m about 3.5 mi. off Troublesome Creek, Anchor Point on 7/20/76. Station 1.

Test Diameter (mm)	Frequency of *S. drobachiensis*	Frequency of *S. pallidus*	Total
29		1	1
39	1		1
40	2		2
41	2		2
42	3		3
43	3		3
44	4		4
45	3	1	4
46	5	3	8
47	1		1
48	2		2
49	2	2	4
51		5	5
52		2	2
53		2	2
54		2	2
55		2	2
57		1	1
58		1	1
59		1	1
68		1	1

S. drobachiensis

$n = 28$

$\bar{x} \pm s = 44.2 \pm 2.7$ mm

S. ? *pallidus*

$n = 24$

$\bar{x} \pm s = 51.5 \pm 6.9$ mm

Pooled Data

$n = 52$

$\bar{x} \pm s = 47.6 \pm 6.2$ mm

Appendix C-4b. Size data for Strongylocentrotus spp. in 14 m about 2.5 mi. off Troublesome Creek, Anchor Point on 7/29/76. Station 2.

Test Diameter (mm)	Frequency of S. drobachiensis	Frequency of S. ? pallidus	Total
17	1		1
21	1		1
29	4		4
30	4		4
31	4		4
32	5	1	6
33	6		6
34	7		7
35	4		4
36	6		6
37	10		10
38	5	2	7
39	4		4
40	4		4
41	4		4
43	3	4	7
44	5	1	6
45	1		1
46		1	1
47	2		2
48	3		3
50	1	1	2
51	1		1

S. drobachiensis
$n = 85$
$\bar{x} \pm s = 36.7 \pm 6.0$ mm

S. ? pallidus
$n = 10$
$\bar{x} \pm s = 42.0 \pm 4.9$ mm

Pooled Data
$n = 95$
$\bar{x} \pm s = 37.3 \pm 6.1$ mm

Appendix C-4c. Size data for *Strongylocentrotus* spp. in 14.6 m off the Anchor Point Light on 7/22/76. Station 3.

Test Diameter (mm)	Frequency of *S. drobachiensis*	Frequency of *S. ? pallidus*	Total
18	1	0	1
25	2	0	2
27	1	0	1
29	1	0	1
30	1	0	1
31	2	0	2
32	5	0	5
33	7	0	7
34	3	0	3
35	6	0	6
36	7	0	7
37	13	0	13
38	6	0	6
39	3	0	3
40	4	0	4
41	3	0	3
42	3	2	5
43	1	0	1
44	1	1	2
45	0	1	1
46	1	1	2
47	0	6	6
48	0	2	2
49	1	2	3
50	0	2	2
51		2	
53		2	
55		1	
56		1	

S. drobachiensis
$n = 72$
$\bar{x} \pm s = 35.9 \pm 4.8$ mm

S. pallidus
$n = 23$
$\bar{x} \pm s = 48.4 \pm 3.7$ mm

Pooled Data
$n = 95$
$\bar{x} \pm s = 39.0 \pm 7.0$ mm

Appendix C-4d. Size data for Modiolus modiolus off Anchor Point Light in 14.6 m on 7/22/76. Station 3.

Shell Length (mm)	Frequency	Shell Length (mm)	Frequency
68	1	98	3
69	1	99	1
75	1	100	2
76	1	102	1
78	1	105	4
80	3	106	1
82	1	107	1
83	3	108	2
84	1	109	2
92	2	110	3
93	2	112	1
95	1	113	1
96	1	115	1
97	6	117	3

$n = 51$

$\bar{x} \pm s = 97.0 \pm 12.9$ mm

Appendix C-4e. Density data; Modiolus modiolus; 2.5 mi. off Anchor Point Light in 14.6 m on 7/22/76. Station 3.

Number per $0.25\ m^2$ Quadrat	Number of Quadrats	Number of Individuals
1	4	4
2	2	4
3	2	6
4	0	0
5	1	5
6	0	0
7	1	7
Total	10	26

$\bar{x} \pm s$ = 2.6 ± 2.0 individuals/quadrat.

Density = 10.4 individuals/m^2.

Appendix C-4f. Abundance data for some sea stars in 20 m about 3.5 mi. off Troublesome Creek, Anchor Point on 7/20/76. Station 1.

	Quadrat (Length x Width)			
Species	20 x 1 m	10 x 1 m	10 x 1 m	No./sq.m.
Crossaster papposus	0	0	1	0.025
Evasterias troschelii	0	0	1	0.025
Henricia sanguinolenta	7	5	5	0.425

Appendix C-4g. Size data for <u>Evasterias troschelii</u> in 20 m about 3.5 mi. off Troublesome Creek, Anchor Point, on 7/20/76. Station 1.

Maximum Radius (mm)

260	315	270	300

$\bar{x} \pm s = 286.3 \pm 25.6$ mm

Appendix C-4h. Feeding observations at Anchor Point-Troublesome Creek in July 1976.

Predator Species	Type of Observation	Number	Depth (m)	Prey Species
Scyra acutifrons	Direct	1	20	Saxidomus gigantea
Evasterias troschelii	Direct	2	20	Modiolus modiolus
Paguridae, unid.	Direct	Numerous		egg masses of Fusitriton and Neptunea
Solaster dawsoni	Direct	1	14	Cucumaria miniata
Evasterias troschelii	Direct	1	14	Saxidomus gigantea
Solaster dawsoni	Direct	1	11	Cucumaria miniata
Crossaster papposus	Direct	1	11	Flustrella gigantea
Cribrinopsis similis	Direct	1	11	Strongylocentrotus droebachiensis
Henricia sanguinolenta	Direct	Several	20	unid. yellow sponge
	Direct	Several	12.8	unid. yellow sponge
Orthasterias koehleri	Direct	2	12.8	Balanus nubilus
Pteraster tesselatus	Direct	1	12.8	unid. yellow sponge
Strongylocentrotus spp.	Direct	Numerous	12.8	red algae

APPENDIX C-5

Iniskin Bay 8/23/76 Time: 1215-1315
Tide: +14.0 ft MLLW Depth: -3 to -4 ft
Location: Northeast of Iniskin Rock Dive Depth: 17-18 ft.

ALGAE-Chlorophyta		
? *Monostroma* sp.	uncommon	shallow boulders
Spongomorpha sp.	common	shallow boulders and ridges
ALGAE-Phaeophyta		
Agarum cribrosum	uncommon	rocks and flats
Alaria marginata	abundant	rocks and flats
Desmarestia aculeata	uncommon	rocks
D. viridis	abundant	rocks and flats
Laminaria groenlandica	abundant	rocks and flats
Ralfsia pacifica	uncommon	rocks and flats
ALGAE-Rhodophyta		
Constantinea subulifera	common	rocks and flats
Corallina sp.	uncommon	2 spp., boulders and rocks
Encrusting coralline alga	abundant	2 spp., boulders and flats
Halosaccion glandiforme	uncommon	shallow boulders
? *Lithothrix* sp.	uncommon	boulders
Odonthalia kamschatica	abundant	boulders, rocks and flats
Phycodrys sp.	abundant	rocks and flats
Porphyra sp.	uncommon	shallow boulders
Pterosiphonia? bipinnata	abundant	boulders, rocks and flats
Rhodoglossum affine	uncommon	boulders and rocks
Rhodymenia palmata	uncommon	boulders
Rhodymenia sp.	uncommon	boulders and rocks
PORIFERA		
Halichondria panicea	uncommon	on *Constantinea* and encrusting coralline algae
Hymendectyon lyoni	common	on rocks and *Modiolus*
CNIDARIA-Anthozoa		
Aciniaria, unid.		
Anthopleura ? *xanthogrammica*	uncommon	banded tentacles

CNIDARIA-Hydrozoa

Abietinaria inconstans		
Orthopyxis compressa		
Plumularia setacea	uncommon	
Polyorchis sp.	common	in water column; 24 gonads

CNIDARIA-Scyphozoa

Haliclystis sp.	uncommon	

ANNELIDA-Polychaeta

Potamilla sp. 1	uncommon	small patches
Flabelligera infaunadibularis		
Serpulidae, unid.	common	tiny, red tentacles, on rocks

ARTHROPODA-Crustacea

Balanus balanus pugettensis		on *Modiolus*
Cirripedia, spat		light cover in patches
Pagurus beringanus		
Pandalidae, unid.		purple
Pugettia gracilis	common	in algae

MOLLUSCA-Gastropoda

Collisella pelta	common	
C. scutum	common	generally small
Doridacea, unid.	common	white, with numerous small yellow tubercules
Margarites olivaceus		
Natica clausa	uncommon	in sand pockets
Neptunea lyrata		
Trichotropis insignis		

MOLLUSCA-Pelecypoda

? *Entodesma* sp.		
Hiatella sp.		
Modiolus mosiolua	common	in depressions

MOLLUSCA-Polyplacorphora

Katharina tunicata		
Mopalia ? *ciliata*		
Tonicella insignis		
T. lineata	common	

ECTOPROCTA

? Rhynchozoon sp.	uncommon	
Tricellaria sp.	common	in Constantinea
ECHINODERMATA-Asteroidea, unid.	uncommon	juvenile
ECHINODERMATA-Echinoidea		
Strongylocentrotus drobachiensis	uncommon	
ECHINODERMATA-Holothuroidea		
Eupentacta ? quinquesemita	common	in Modiolus clumps and algal haperta
CHORDATA-Pisces		
Hexagrammos decagrammus	common	8-14 inches

Habitat Notes:

Visually dominated by Laminaria and Alaria; encrusting coralline algae covered about 50% or less of the rock surfaces; the visually dominant invertebrate was Modiolus modiolus.

Substrate:

Bedrock with scattered boulders and patches of shelly sand; much of the rock surface was bare and exposed.

APPENDIX C-6

Iniskin Bay 8/23/76 Tide: +12.5 ft

Time: 1350-1430 MLLW Depth: -17.5 ft Dive Depth: 30 ft

Location: 200 yds south of Iniskin Rock

ALGAE-Phaeophyta		
Agarum cribrosum	uncommon	small
Desmarestia aculeata	"	
D. ligulata	"	
Laminaria groenlandica	"	
ALGAE-Phodophyta		
Constantinea simplex	"	stunted
C. subulifera	"	
Encrusting coralline alga	"	
Halosaccion glandiforme	"	
Odonthalia kamschatica	"	
Rhodophyta, unid. (fleshy)	"	
Rhodymenia pertusae	"	
PROTOZOA-Foraminifera		
Gromia oviformis		
PORIFERA		
Halichondria panicea	common	
Suberites ficus	uncommon	

Porifera, unid. (pebbled, yellow)	abundant	covering entire surface of some boulders, growing over barnacles
Porifera, unid. (pock marked, orange-red)	uncommon	overgrowing barnacles
CNIDARIA-Hydrozoa		
Corynidae, unid.	uncommon	
Hydractinia sp.	"	
Sertularia cupressoides	common	
S. tenera		fine pink
Thuiaria cylindrica	common	heavy yellow
ANNELIDA-Polychaeta		
Autolytus sp.		
Chone gracilis		
Cirratulus cirratus		
Nicomache personata		
Pectinaria (Cistenides) granulata		
Potamilla sp. 2	common	
Potamilla sp. 3		no eyes
Terebellidae, unid.		
ARTHROPODA-Crustacea		
Balanus crenatus	abundant	
B. ? *nubilus*	"	
B. rostratus alaskensis	"	covering boulders
Elassochirus gilli	"	large
E. tenuimanus	common	medium sized
Hyas lyratus	uncommon	

Oregonia gracilis	"	
Pagurus beringanus	"	
P. ? tanneri	"	in *Suberites*

MOLLUSCA-Polyplacophora

Amicula sp.	uncommon	
Ischnochiton ? albus		
Mopalia sp.		
Tonicella insignis	uncommon	
T. lineata	common	

MOLLUSCA-Pelecypoda

Hiatella arctica	common	under rocks
Modiolus modiolus		shell only
Musculus discors		" "
Yoldia myalis		" "

MOLLUSCA-Gastropoda

Boreotrophon pacificus		
Fusitriton oregonensis	common	spawning pimpled egg cases
Natica ? aleutica	uncommon	common spawning, burrowing in
Neptunea lyrata	common	shelly silt
Puncturella galeata		
Trichotropis insignis		

ECTOPROCTA

Alcyonidium ? mammillatum		
A. ? pedunculatum		
A. polyoum	uncommon	on barnacles
Carbasea carbasea	common	
Costazia ventricosa	common	
Eucratea loricata		
Flustrella corniculata		
Microporella sp.		
Myriozoella ? plana		
Parasmittina sp.	abundant	on rocks and barnacles
?Rhamphostomella sp.	abundant	on rocks and barnacles
Terminoflustra membranaceo-truncata	uncommon	

ECHINODERMATA-Asterozoa

Crossaster papposus	common	
Henricia tumida	uncommon	
Leptasterias polaris var. acervata	abundant	forma acervata, feeding on barnacles and Pectinaria
Ophiopholis aculeata	common	under rocks and in crevices

ECHINODERMATA-Echinoidea

Strongylocentrotus drobachiensis	abundant	very large, masking heavily with shell and algae
S. ? pallidus	common	same note

HEMICHORDATA-Tunicata

Didemnum sp.	uncommon	

CHORDATA-Pisces

Cottidae, unid.	uncommon	small
Hexagrammos stelleri	common	

HABITAT NOTES:

Substrate dominated by barnacles, pebbled yellow sponges and encrusting bryozoans. Other important invertebrates: *Strongylocentrotus drobachiensis*, *Elassochirus gilli*, *E. tenuimanus*, *Leptasterias polaris* var. *acervata* forma *acervata*, and *Halichondria panicea*. Under rock fauna sparse.

Substrate: Cobbly bottom with large pockets of shelly silt, and cattered boulders, shell debris important, moderate drift algae, moderate barnacle cover.

Appendix C-6a. Size data for selected echinoderms from south of Inishin Rock, Iniskin Bay, 8/23/76

Asteroidea [1]											$\bar{x} \pm s$
Crossaster papposus	47	53	55	44							49.8 ± 5.1
Henricia tumida	31	26	19	19							23.8 ± 5.9
Lepasterius polaris acervata forma *acervata*	119	123	112	102	126	114	128	116	111	125	
	118	103	100	115	110	103	124	133	126	108	
	140	126	109	110	128	104	137	137	125	110	
	102	118	100	98	75	113	112	134	115	145	
	115	73	113	108	125	132	132	102	135	115	113.0 ± 20.7
Echinoidea [2]											
Stronglycentrotus drobachiensis	86	92	90	86	84	90	86	82	81	81	
	73	67	66	63	53	52	49	50	46	48	
	39										69.7 ± 17.6
S. ?pallidus [3]	83	83	83	79	72	71					78.5 ± 5.6

[1] radius to tip of longest ray (mm)

[2] maximum diameter of test (mm)

[3] specimens were sextually mature and ripe

APPENDIX C-6b

Aperture length of gastropods from south of Iniskin Rock, Iniskin Bay, 8/23/76

Aperture Length (mm)	*Fustriton oregonensis*	*Neptunea lyrata*
29	1	
30	0	
31	1	
32	1	
33	0	
34	0	1
35	1	1
36	1	
37	0	
38	1	
39	1	
40	4	
41	2	
42	1	
43	4	
44	1	
45	2	
46	0	
47	0	
48	1	
n	22	2
$\bar{x} \pm s$ (mm)	39.9 ± 4.8	34.5

APPENDIX C-7

Iniskin Bay	8/24/76	Tide: +13.9 ft
Time: 1245-1315	MLLW Depth: -10.1 ft	Dive Depth: 24 ft

ALGAE-Phaeophyta		
Laminaria groenlandica	uncommon	some attached, mainly drift algae
CNIDARIA-Hydrozoa		
? *Hybocodon prolifer*	abundant	on stones; to 15 cm high
Hydractinia sp.		on hermit shells, poss. new species
Sertularella rugosa		
Sertularia similis		
Sertulariidae, unid.		
Thuiaria cylindrica	common	on rocks
ANNELIDA-Polychaeta		
Potamilla sp. 2	common	very large, with bryozoan on tube (? *Alcyonidium*)
ARTHROPODA-Xrustacea		
Balanus balanus	common	on stones and shells
Pagurus beringanus	common	large
P. ochotensis	uncommon	large
MOLLUSCA-Gastropoda		
Aeolidida, unid.	common	feeding on ? *Hybocodon* and spawning on stalks

MOLLUSCA-Gastropoda

Lacuna crassior		
Neptunea lyrata	common; 0.1/m^2	

MOLLUSCA-Pelecypoda

Clinocardium nuttallii		Shell only
Macoma brota		Shell only
M. calcarea		Shell only
M. obliqua		Shell only
Musculus vernicosus		Shell only
Mya priapus		Shell only

ECTOPROCTA

Alcyonidium ? pedunculatum	abundant	crenulate, fairly large
A. polyoum		on Potamilla sp. 2
Bicrisia sp.		
Carbasea carbasea	common	
Cystisella bicornis		
Flustrella corniculata		
Hippothoa hyalina		
? Pachyegis brunnea		
? Tegella aquilirostris		
Terminoflustra membranaceo-truncata	common	

ECHINODERMATA-Asteroidea

Leptasterias polaris var. acervata	common; 0.7/m^2	5 mm juvenile observed

CHORDATA

Tunicata, unid	common	white, colonial, on rocks, and <u>Alcyonidium</u> ? <u>pedunculatum</u>

CHORDATA-Pisces

<u>Hexagrammos</u> <u>stelleri</u>	common	small

Substrate: Clay silt bottom, rather sticky with shell debris and scattered cobble common.

APPENDIX C-7a

Size data for _Leptasterias_ _polaris_ var. _acervata_ from off Rocky Point, Iniskin Bay, 8/24/76

Maximum Radii (mm)

40	126	33	65
93	75	50	72
55	70	85	63
85	105	136	126
26			

$\bar{x} \pm s = 76.8 \pm 32.6$ mm

$n = 17$

APPENDIX C-8

Chinitna Bay	8/21/76	Time: 1930-2015
Tide: +8.6 ft		MLLW Depth: -13.4 to -16.4 ft
Location: Off Spring Point		Drive Depth: 22-25 ft

ALGAE-Rhodophyta

Callophyllis sp.	abundant	on cobbles and barnacles
Encrusting coralline alga	very abundant	on rock and
Hildenbrandia sp.	common	
Odonthalia kamtschatica	scattered	on cobble and barnacles
? *Opuntiella* sp.	abundant	on boulders and cobble
Phycodrys sp.	abundant	on boulders and cobble
Rhodophyta, unid. (filamentous)	scarce	on cobble and epiphyte of reds
Rhodophyta, unid. (fleshy)	scarce	on cobble and barnacles

ALGAE-Phaeophyta

Agarum cribrosum	scarce	on tops of boulders
Desmarestia ligulata	abundant	on cobble
Lamimaria groenlandica	scarce	on tops of boulders

PORIFERA

Esperiopsis quatsinoensis	common
Halichondria ? *panicea*	common
Mycale lingua	common

CNIDARIA-Anthozoa

Cribrinopsis similis

CNIDARIA-Hydrozoa

Abietinaria filicula	abundant
A. gigantea	uncommon
A. variabilis	common
Halecium sp.	
Grammaria abietina	common
Sertularella tenella	
Sertularia cupressoides	common

NEMERTEA, unid	large red, in *Bidenkapia* head

ANNELIDA-Polychaeta

Lepidonotus helotypus	in *Bidenkapia* head
Potamilla sp.	

ARTHROPODA

Balanus crenatus		some areas with spat
Balanus rostratus alaskensis	dominant	
Elassochirus gilli	common	
Lebbeus ? gracilis		
Pagurus beringanus		
P. ? tanneri		
? Pandalidae		juveniles

MOLLUSCA-Gastropoda

Beringius kennicotti		
Boreotrophon truncatus pacificus	uncommon	under rocks
Buccinum glaciale	abundant	under rocks and in bryozoans
Cryptobranchiasp.	uncommon	under rocks
Fusitriton oregonensis	uncommon	spawning, small egg masses
Margarites pupillus	abundant	
Natica eggs	common	
Neptunea lyrata	uncommon	spawning
Puncturella multistriata		
Trichotrophis insignis		
Velutinavelutina		
Volutopsius castaneus	common	shell only

MOLLUSCA-Pelecypoda

Clinocardium californiense		shell only
Modiolus modiolus	uncommon	shell only, small shell
Musculus discors		shell only
Nuculana sp.	uncommon	shell only
Pododesmus macroschisma	common	

MOLLUSCA-Polyplacophora

Cryptochiton stelleri	uncommon	
Ischnochiton albus		
I. trifidus		
Mopalia ciliata		
Tonicella insignis	abundant	on rocks
T. lineata	abundant	on rocks

ECTOPROCTA

Alcyonidium ? pedunculatum	common	
Bidenkapia spitsbergensis	common	tan, broader frills
Carbasea carbasea	common	
Costazia ? procumbens	common	

C. ventricosa	uncommon	
Dendrobeania murrayana	common	
Flustrella gigantea	common	
Heteropora sp.	abundant	
Hippothoa hyalina	common	
? *Pachyegis* sp.	abundant	on barnacles
? *Parasmittina* sp.	abundant	on barnacles
? *Rhamphostomella* sp.	uncommon	head 10 cm in diameter

ECHINODERMATA-Asteroidea

Crossaster papposus	common	
Henricia leviusculus	common	
H. sanguinolenta		
Leptasterias polaris var. *acervata*	common	feeding on barnacles

ECHINODERMATA-Holothuroidea

Psolus sp.	uncommon	large

ECHINODERMATA-Ophiuroidea

Ophiopholis aculeata	abundant	in bryozoans, under and around rocks

CHORDATA-Tunicata

Tunicata, unid.	uncommon	small solitary, unstalked, on sides of rock

CHORDATA-Pisces

Pleuronectiformes, unid.	uncommon	
Hexagrammos stelleri	abundant	bold, feeding and schooling around divers
Ronquilus jordani	uncommon	in holes around rocks

Habitat notes: Assemblages heavily dominated by suspension feeders, i.e. *Balanus* spp., bryozoans, hydroids, sponges, *Ophiopholis*; algae very light.

Substrate - Cobble bottom with scattered boulder, patches, boulders up to 6' high, light silt on all surfaces.

Appendix C-8a. Size measurements for dominant macro-invertebrates in subtidal area of Spring Point, Chinitna Bay, 8/21/76.

SPECIES

Crossaster papposus (maximum radius, mm): 55, 68, 55, 51, 48, 55. $\bar{x} \pm = 55.3 \pm 6.8$ mm.

Fusitriton oregonensis (aperture length, mm): 46, 47, 48. $\bar{x} \pm s = 47.0 \pm 1.0$ mm.

Henricia spp. (maximum radius, mm): 52, 40, 76, 43, 95, 46, 31, 35, 35, 73, 26, 72. $\bar{x} \pm s = 52.0 \pm 21.8$ mm.

Leptasterias polaris acervata (maximum radius, mm): 34, 125, 88, 150, 135, 115, 122, 134, 130, 122, 128, 145, 132, 130, 118, 122. $\bar{x} \pm s = 120.6 \pm$ mm.

Neptunea lyrata (aperture length, mm): 37, 40, 37, 29, 30, 28, 30. $\bar{x} \pm s - 33.0 \pm 4.8$ mm.

Strongylocentrotus spp. (maximum diameter, mm): 75, 79. $\bar{x} = 75.0$ mm.

APPENDIX C-9

Chinitna Bay	8/22/76	Tide: +11.7 ft
Time: 1430-1600	MLLW Depth: 4 to -10 feet	Dive Depth: 16-22 ft

Location: Clam Cove Reef

ALGAE-Phaeophia		
Alaria marginata	dominant	
Desmarestia aculeata	uncommon	
Laminaria groenlandica	dominant	
Ralfsia pacifica	common	
ALGAE-Rhodophyta		
Constantinea sp.	uncommon	
Coralline sp.	common	
encrusting corraline alga	dominant	2 species
Hildenbrandia sp.	uncommon	
Odonthalia kamschatica	common	
CNIDARIA-Hydrozoa		
Abietinaria inconstans	common	with branching hydrocladia
Eudendrium vaginatum	common	
Plumularia setacea	common	
Sertularia cupressoides	uncommon	
CNIDARIA-Anthozoa		
Anthopleura ? xanthogrammica	uncommon	
Tealia crassicornis	uncommon	

ANNELIOA-Polychaeta		
Lepidonotus helotypus		
Neris sp.		
Potamilla sp.	abundant	forming mats in pockets on rock
ARTHROPODA-Crustacea		
Elassochirus gilli		
E. tenuimanus		
Hapalogaster mertensii		
Pagurus beringanus		
MOLLUSCA-Gastropoda		
Beringius kennicotti		
Boreotrophon clathrus		
Buccinum glaciale		shell only, on hermit crabs
Collisella ochracea	common	small, flatfish
Cryptobranchia sp.	uncommon	
dorid nudibranch	uncommon	white, tuberculate on _Laminaria_ blade
Lacuna vincta		
Margarites helicinus		
M. pupillus	common	
Neptunea lyrata	uncommon	spawning
Nucella lima		
Puncturella multistriata		
Trichotrophis cancellata	uncommon	
T. insignis	abundant	on sides of rock

Velutina rubens		
V. velutina		
Volutharpa ampullacea	uncommon	
MOSSUSCA-Pelecypoda		
Modiolus modiolus	scarce	in *Potamilla* mats
Musculus vernicosus	uncommon	on *Desmarestia*, *Eudendrium* and *Odonthalia*
Mya sp.	uncommon	in *Potamilla* mats
MOLLUSCA-Polyplacorphora		
Cryptochiton stelleri	uncommon	
Mopalia ciliata		
Tonicella lineata	abundant	
ECTOPROCTA		
Alcyonidium sp.		
Costazia sp.		
Hippothoa hyalina		
Microporella sp.		
Terminoflustra membranaceo-truncata	abundant	
Tricellaria ternata	uncommon	on rocks and Constantinea
ECHINODERMATA-Asterozoa		
Solaster ?endeca	uncommon	110 mm radius
S. stimpsoni		

CHORDATA-Tunicata

Aplidium sp.		
? _Distaplia_ _occidentalis_		
? _Pyura_ sp.	uncommon	whitish w/red apertures, with eggs
Tunicata, encrusting colonial	uncommon	2 spp-one gold, one yellow-brown
Tunicata, solitary stalked	uncommon	small, white

CHORDATA-Pisces

Hexagrammos _decagrammus_

HABITAT NOTES:

Visually dominated by _Laminaria_ and _Alaria_ in moderate abundance and biomass, understory by encrusting coralline algae and _Potamilla_ sp.

Productive area; no macroherbivores, abundant microherbivores. Main susension feeders - _Potamilla_ and _Trichotropis_ _insignis_.

Substrate: Bedrock with scattered boulders and patches of shell debris: surface generally flat, little relief such as surge channels, etc. leptopel in water dense.

Appendix C-9a. Density of dominant macrophytes on Clam Cove Reef, Chinitna Bay, 8/22/76

Replicate [a]	*Alaria marginata*	*Laminaria groenlandica*
1	12	67
2	2	91
3	10	98
$\bar{x}$	8.0	85.3
s	5.3	49.5
No./m^2	1.6	17.1

a 5 x 1 m quadrats

Appendix C-9b. Relative cover (C) and abundance (N) of macrophytes in 1/4 m^2 quadrats in the subtidal zone on Clam Cove Reef, Chinitna Bay, 8/22/76

	1	2	3	4	5	6	7	8	9	10	11	12	$\bar{x} \pm s$
Alaria marginata (C)	50%	40%	30%	35%	0	15%	40%	20%	20%	30%	70%	75%	35.4 ± 21.8%
A. marginata (N)	14	4	0	0	0	0	1	3	2	4	5	5	3.2 ± 4.0
Constantinea simplex (C)	0	2%	0	0	0	0	2%	0	0	0	2%	0	0.5 ± 0.9%
Corallina sp. (C)	0	0	0	0	0	0	0	0	0	0	2%	0	0.2 ± 0.6%
encrusting coralline algae (C)	40%	30%	60%	65%	65%	70%	35%	45%	30%	60%	45%	70%	51.3 ± 15.4%
Hildenbrandia sp. (C)	0	0	0	0	0	0	0	0	0	0	5%	0	0.4 ± 1.4%
Laminaria groenlandica (C)	40%	20%	45%	75%	100%	60%	20%	70%	70%	20%	15%	25%	46.7 ± 27.9%
L. groenlandica (N)	13	14	4	3	5	13	1	7	13	1	5	0	6.6 ± 5.3
Odonthalia kamschatica (C)	0	25%	0	3%	3%	5%	0	10%	3%	15%	10%	3%	6.4 ± 7.5%
Ralfsia pacifica (C)	0	0	0	0	0	2%	10%	15%	10%	15%	5%	10%	5.6 ± 6.1%
Rhodymenia palmata (C)	0	0	0	0	0	0	0	0	0	2%	0	0	0.2 ± 0.6%

Substrate: rock
Depth: 16 ft. (4.9 m)

Appendix C-9c. Relative cover (C) and abundance (N) of species in 1/4 m^2 quadrats from the subtidal zone on Clam Cove Reef, Chinitna Bay, 8/22/76

	1	2	3	4	x + 5	Density (No./m^2)
Alaria marginata (adults) (C)	20%	0	25%	20%	16.3 ± 11.1%	
(Adults) (N)	0	0	1	0	0.3 ± 0.5	1.0
(juveniles)(N)	0	0	2	0	0.5 ± 0.1	2.0
Corallina sp. (C)	0	0	2%	0	0.5 ± 0.1%	
Encrusting coralline algae (C)	70%	40%	60%	20%	47.5 ± 22.2%	
Laminaria groenlandica						
(adults) (C)	80%	65%	65%	75%	71.3 ± 7.5%	
(adults) (N)	2	4	2	4	3.0 ± 1.5	12.0
(juveniles) (N)	0	0	5	1	1.5 ± 3.5	6.0
Odonthalia kamschatica (C)	0	5%	2%	5%	3.0 ± 2.4%	
Ralfsia pacifica (C)	5%	15%	15%	1%	9.0 ± 7.1%	
Abietinaria inconstans (C)	5%	2%	5%	0	3.5 ± 2.4%	
Collisella ochracea (N)	1	1	0	1	0.8 ± 0.5	3.0
Anthopleura ? xanthogrammica (N)	0	1	0	0	0.3 ± 0.5	1.0
Aplidium sp. (C)	2%	0	0	0	0.5 ± 1.0	
Eudendrium vaginatum (C)	0	1%	0	5%	1.5 ± 2.4%	
Margarites pupillus (N)	1	0	0	0	0.3 ± 0.5	1.0
M. helicinus	P[a]	P	0	0		
Modiolus modiolus (N)	0	2	0	0	0.5 ± 1.0	2.0
Musculus vernicosus	0	P	0	P		
Pagurus sp. (N)	3	1	5	0	2.3 ± 2.2	9.0
Potamilla sp (C)	0	50%	35%	5%	22.5 ± 24.0%	
Tonicella lineata (N)	14	11	16	7	12.0 _ 3.9	48.0
Trichotropis insignis (N)	7	3	0	0	2.5 ± 3.3	10.0
Boreotrophon ? Clathratus (N)	1	0	0	0	0.3 ± 0.5	1.0
Shell debris	0	0	0	75%	18.8 ± 37.5	

Substrate: Bedrock with scattered boulders and patches of shell debris

Depth: 18-22 ft (5.5-6.7 m)

[a] P - present

APPENDIX D

STATION DATA FOR QUANTITATIVE INFAUNAL SAMPLES FROM

LOWER COOK INLET

Appendix D-1. Number of infaunal species in 44 sq. cm. cores in sandy intertidal zone at base of Homer Spit, 5/13/76.

	NUMBER	
ELEVATION (feet below MLLW)	0 to -1	-4
Number of Cores	6	6
SPECIES	1/	
Cumacea, unid		4
Eohaustorius spp		1
Hippomedon sp. A		4
Macoma sp.		1
Nephtys nr. *caeca*		1
Paraphoxus obtusidens		1
Psephidia lordi		1
Scoloplos armiger		2
Spiophanes bombyx		2

Total number or organisms 17

1/ No organisms in cores

Appendix D-2. Number of infaunal species in 44 sq. cm. cores in sandy intertidal zone at Seafair Beach, 5/31/76.

	NUMBER	
ELEVATION (feet below MLLW)	0 to -1	-4
Number of Cores	6	6
SPECIES	1/	
Eohaustorius spp.		2
Hippomedon sp. A		6
Magelona sacculata		3
Nephtys nr. *parva*		1
Paraphoxus obtusidens		1
P. o. major		1
Spiophanes bombyx		2

Total number of organisms 16

1/No organisms in cores

Appendix D-3. Number of infaunal species in 44 sq. cm. cores in sandy intertidal zone at Whiskey Gulch, 5/12/76.

	NUMBER			
ELEVATION (feet below MLLW)	0	0 to -1	-1	-2
Number of Cores	3	6	6	6
SPECIES				
Anisogrammarus pugettensis	1			
Anonyx sp. A		1		
Cumacea, unid				1
Eohaustorius spp.	4	1		9
Nephtys nr. *parva*	1		1	
Paraphoxus obtusidens major	4	1		5
Scolelepis sp.			3	
Subtotal	10	3	4	15
Total number or organisms 32				

Appendix D-4. Number of infaunal species in 44 sq. cm. cores in sandy intertidal zone at Deep Creek, 5/17/76.

	NUMBER		
ELEVATION (feet below MLLW)	+2	-2	-3
Number of Cores	3	3	6
SPECIES	[1]	[1]	
Eohaustorius spp.			36
Eteone nr. *longa*			1
Paraonidae, unid.			2
Paraphoxus obtusidens major			1
Scoloplos armiger			2
Spio filicornis			2

Total number of organisms 44

[1] No organisms in cores

Appendix D-5. Number of infaunal species in 44 sq. cm. cores in sandy intertidal zone at Clam Gulch, 5/14/76.

	NUMBER	
ELEVATION (feet below MLLW)	-2	-4
Number of Cores	6	12
SPECIES		
Eohaustorius spp.	23	52
Gammaridea #3		1
Paraphoxus obtusidens	2	
Paraonidae, unid.		6
Scolelepis sp.		1
Spio filicornis		2
Subtotal	25	62

Total number of organisms 87

Appendix D-6. Number of infaunal species in 44 sq. cm. cores in sandy intertidal zone at Amakdedori, 7/13/76.

		NUMBER		
ELEVATION (feet below MLLW)		+1	-2	-3
Number of Cores		3	6	6
SPECIES		1		
Anisogammarus ? *pugettensis*				2
Arenicola marina			1	
Nephtys nr. *parva*			1	1
Orbinella nuda			1	
Siliqua patula (juveniles)			1	3
Scolelepis sp.			5	
Spio filicornis			2	8
Spionidae #5			1	
Subtotal			12	14
Total number of organisms	26			

Appendix D-7. Number of infaunal species in 44 sq. cm. cores in sandy intertidal zone at Chinitna Bay clam Beach, 6/11/76.

		NUMBER	
ELEVATION (feet below MLLW)		-3	-4
Number of Cores		12	6
SPECIES			
Capitella capitata		1	
Eohaustorius spp.		11	3
Eteone nr. *longa*		2	1
?*Neomysis* sp.		2	
Nephtys nr. *caeca*		1	
N. nr. *parva*		1	
Subtotal		18	4
Total number of organisms	22		

Appendix D-8. Number of infaunal species in 44 sq. cm. cores in sandy inter-tidal zone at Polly Creek, 7/13/76.

	NUMBER	
ELEVATION (feet below MLLW)	-1	-3
Number of Cores	6	6
SPECIES	[1]	
Archaeomysis grebnitzkii		3
Eohaustorius spp.		4
Scolelepis sp.		fragments

Total number of organisms 7

[1] No organisms in cores

AIRBORNE MULTISPECTRAL
MAPPING OF THE INTERTIDAL ZONE
OF SOUTHERN ALASKA

N.E.G. ROLLER, F.C. POLCYN

RESEARCH UNIT 428

DECEMBER 1977

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16. Abstract

Multispectral analysis was performed on a data set collected by a low flying aircraft at three sites in the Gulf of Alaska, i.e., Zaikof Bay, Latouche Point and Cape Yakataga for the purpose of mapping intertidal algal communities.

Both supervised and unsupervised processing procedures were employed. It is possible to separate vegetation into broad spatial zones representing either species of algae or species associations or simply vegetation density classes. Clustering techniques represent the most effective way to extract training signatures. A minimum of four spectral bands is needed to achieve the recognition performance levels demonstrated in this study. Two channels in the visible (green and red), one in the near-infrared region (~1.0μm) and one in the thermal region were found most useful.

A hypothetical intertidal survey of 1200 miles of Alaska shoreline is outlined with summaries of data collection and processing costs given for the mission using optimum spectral bands.

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PREFACE

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1.0
INTRODUCTION

Our national need for adequate energy supplies necessitates the increased development of our natural resources. At the same time, sensitive biological communities that play valuable ecological roles must be protected.

To insure the protection of these delicate living resources, information is needed so that those communities which would be most easily and adversely affected by the results of energy development activities can be identified prior to impact. Accordingly, a goal of the Outer Continental Shelf Energy Assessment Program (OCSEAP) of the National Oceanic and Atmospheric Administration (NOAA) is to obtain current information about the location and composition of important littoral vegetation communities in the Gulf of Alaska, where development of gas and oil deposits is expected in the near future.

OCSEAP is under the direction of the Environmental Research Laboratories of NOAA and sponsored by the U.S. Department of Interior, Bureau of Land Management.

1.1 BACKGROUND

The environmental baseline data that must be collected consists of information about the distribution of the major littoral habitat types along the Alaskan coastline and the character and abundance of the vegetation within each habitat type. Currently, this data is collected by visual observation from light aircraft, a hazardous and difficult job.

After discussions with Dr. Herbert Bruce, Manager of the Bering Sea-Gulf of Alaska Project Office, Juneau, Alaska and Dr. Steven Zimmerman, a project was initiated in the summer of 1976 which had as its objective a demonstration of the potential of a passive airborne multispectral scanner and associated computer data processing for accomplishing this baseline coastal inventory task. Three sites were selected by Dr. Zimmerman and a coordinated overflight and ground investigation planned and executed in late June. The data collected on that mission was subsequently analyzed by the Environmental Research Institute of Michigan (ERIM) and a digital computer and special software used to map the type and distribution of algae found at the study sites.

The airborne data collection was accomplished using a twin-engined Cessna 310 carrying a 10-channel multispectral scanner that was installed in the aircraft at Anchorage, Alaska. Multispectral data was collected during low tide at the three study sites (1) Zaikof Bay, (2) Latouche Point, and (3) Cape Yakataga. The details of the overflight, the scanner and a catalog of the flight lines collected, altitudes, and headings were reported in the final report "Investigation of Intertidal Zone Mapping by Multispectral Scanner Techniques" 123200-1-F submitted in fulfillment of contract 03-6-022-35225. They are briefly reviewed in Chapter 3.0 of this report.

Processing of the data began at ERIM after converting the digital data, which was stored in high density form on magnetic tape during the aircraft mission, to computer compatible tape. An analysis of the multispectral signatures for the different types of algae was then performed.

There are a variety of procedures that are available to conduct such an analysis depending on the type and amount of information already known about the vegetation. First, if recognizable samples of each species can be located in the scene, spectral signatures can be calculated for each type and the scene can be classified according to well developed statistical criteria. Second, if no prior knowledge exists, computer programs exist to automatically group signal into clusters which can later be correlated to algae type after a classification map has been constructed.

For this analysis, a modified form of supervised classification was chosen. Dr. Zimmerman outlined the general boundaries of the major algal zones in the intertidal region on color aerial photographs.

Areas within each zone to be used as training sets were selected by inspection of signal differences on computer graymaps which resemble black and white air photos. Signatures were then calculated for the training sets which consisted of groups of pixels having a uniform appearance on the graymaps. The spectral signatures were then used to classify the remaining data. To display the classification results, color-coded terrain feature maps were made using ERIM's MIDAS computer with its color ink-jet printer. A computer map was made for each of the three sites and sent to Dr. Zimmerman and his staff. An inventory of the area of each algal type was also made by counting the number of individual picture elements (pixels) representing each algal type. The area of each pixel is known from the altitude of the aircraft and the angular size of the resolution element of the scanner.

Their initial reactions were favorable; the different algal zones appeared to have been correctly mapped. However, because the computer was able to distinguish differences <u>within</u> a zone as well as <u>between</u> zones, additional analysis efforts seemed warranted to determine the basis of these within class differences.

This initial processing effort (Phase I) used only visible and reflected infrared spectral data, whereas thermal infrared data was also available on tape, and its influence on recognition had not yet been analyzed.

Consequently a second processing effort (Phase II) was planned to look into these issues and was carried out at ERIM during a time convenient for Dr. Zimmerman and Ms Joyce Gnagy to be present. They both have personal knowledge of the study sites since they participated in the ground data collection phase which took place coincidently with the aircraft data collection. This report is designed to provide a description of the Phase II processing and a summary of the results obtained in both Phase I and Phase II.

1.2 OBJECTIVES

Under Dept. of Commerce Contract 03-7-022-35208, a Phase II effort was undertaken to complete this investigation of the use of airborne passive multispectral remote sensing techniques for surveying intertidal habitats. The purpose of this follow-on project was to provide a set of processed data from which several things could be learned: first, how accurately can different species of algae be mapped; second, what sensor operation/flight plan parameters have the most bearing on recognition performance; and, third, what computer processing technique is best in terms of combining acceptable recognition accuracy with low cost and good turn-around time? Then, on the basis of these findings determine the optimum method of airborne data collection and computer processing for operationally accomplishing the required coastline inventory task.

In August of 1977, Dr. Zimmerman and Ms Gnagy visited ERIM during which time the additional computer analysis of the data collected in June 1976 was undertaken. Their knowledge of the algal distribution at the study sites was used in the manual selection of training sets to derive spectral signatures. Cluster analysis of the data took place subsequent to their visit at ERIM. The results of these analyses appear in Chapters 4 and 5.

1.3 STUDY SITES

The character of the three study sites that were selected for this project provided the opportunity to observe different species of algae in different physical environments. The Zaikof Bay site on Montague Island represented a typical intertidal area with high algal species diversity, hilly topography and varying slopes. The intertidal area at Latouche Point has a gradual slope so that the algal zonation is relatively quite broad. The Cape Yakataga site is characterized by several large, nearly horizontal benches, each representing almost a mono-specific algal flora. Year to year environmental changes do, however, alter the extent and uniformity of the vegetation communities at each site.

A reference map showing the approximate location of the three study sites in the Gulf of Alaska is shown in Figure 1.

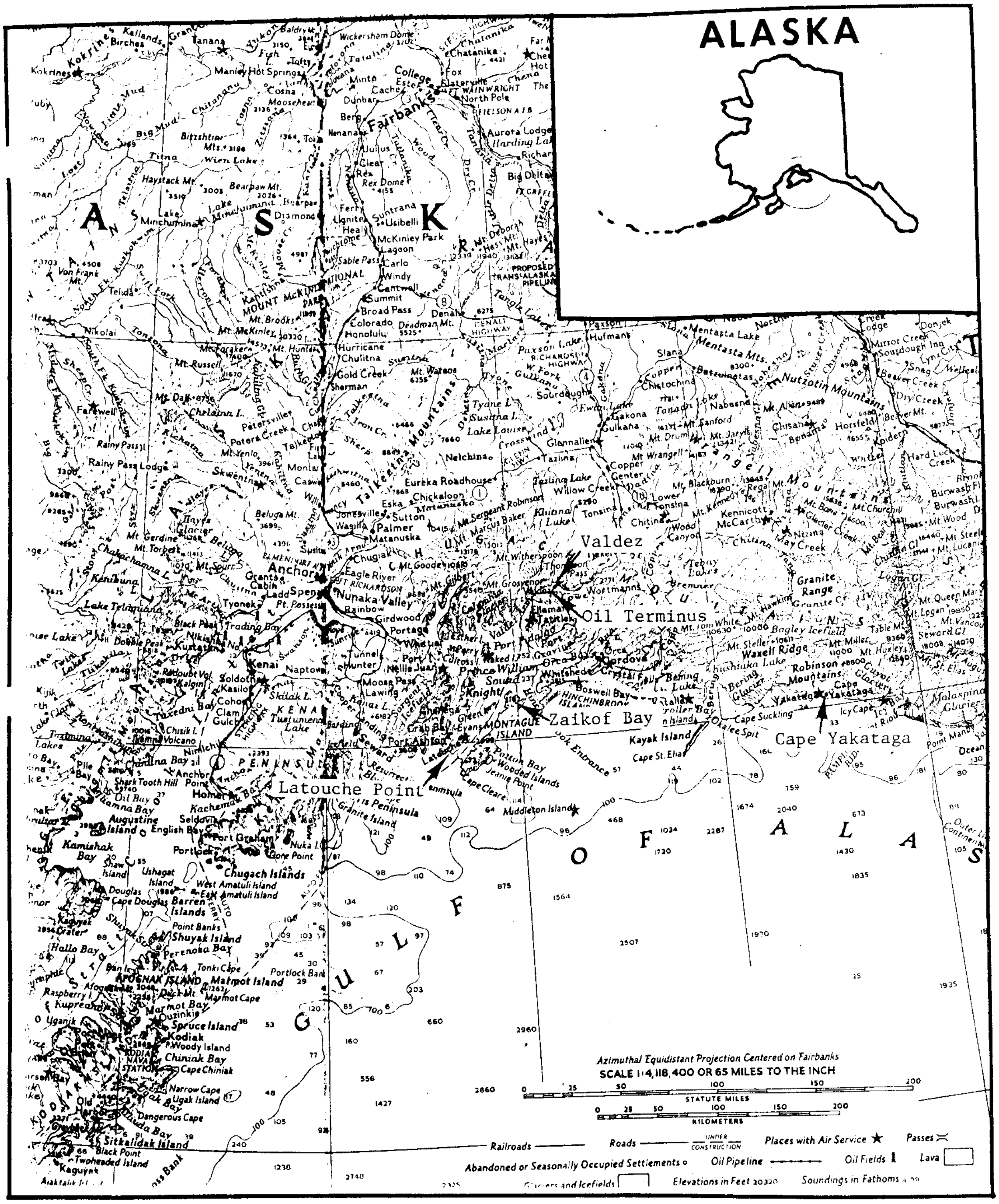


Figure 1. Location of Study Sites

2.0
APPROACH

In order to achieve the overall goal of this study, which is to determine the cost-effectiveness of computer-processed airborne multi-spectral scanner data for intertidal zone mapping in Alaska, a systematic investigation of sensor parameters and associated data processing strategies was undertaken. The advantage of this approach is that a set of boundary conditions are readily identified for each parameter and strategy, which, when considered together, define the most effective operational configuration of the remote sensing system under consideration. Another important benefit is that it permits using a very generalized data collection system, so that initially a wide range of alternative sensor configurations can be considered.

Based on specific experience gained in ERIM's related program of coastal zone macrophyte mapping the the Great Lakes (Wezernak, et.al., 1974; Tanis, 1977), along with our general knowledge of computer data processing techniques, three key information gaps were identified which we felt must be filled in by this study before it would be possible to specify an operational intertidal zone airborne MSS mapping system. In order of priority these three key information gaps were: (1) How much supporting biological field work is necessary, (2) what is the simplest scanner configuration that is effective, and (3) what should the role of the biologist be in the data processing? To answer these questions a three-level project design was developed, with each of the levels roughly corresponding to one of the previously identified information gaps and prioritized accordingly. This plan is outlined in Figure 2. The significance and nature of the three information gaps addressed by the individual levels of the study plan are discussed in the next three sections of the approach (Sections 2.1, 2.2 and 2.3). This background material is then followed by a brief discussion of the organization of the rest of the report (Section 2.5).

LEVEL I: Evaluate supervised and unsupervised methods of computer processing of airborne MSS data.

- compare supervised recognition results produced with and without ground truth.
- compare recognition results produced using both supervised and unsupervised methods.
- compare time and cost required for all three methods.

LEVEL II: Identification of optimum set and number of spectral bands

- On the basis of spectral signature analysis, identify the best reflected visible and near-infrared bands.
- compare recognition results to determine the relative performance of
  a. reflected bands only
  b. thermal band only
  c. reflected bands plus thermal
- Insofar as possible determine the effect of data quality on band selection.

LEVEL III: Compare Interactive vs Batch modes of computer processing plus data displays

- compare the time and cost associated with each mode of data processing.
- compare ease of interpretation and analysis of various data displays.

FIGURE 2. Study Plan for Alaska Intertidal Zone Mapping Project.

2.1 LEVEL I: SUPERVISED VS. UNSUPERVISED PROCESSING

A major factor affecting the cost and speed of remote sensing data processing is the amount and type of human intervention required. If it is necessary for someone to analyze in detail the results of every step in the data-handling stream, and there are several steps, the processing of a single data set can quickly become both laborious and time-consuming. Matters are further complicated if interaction between field personnel located at a remote site is required with persons working at the data analysis center. These problems in one form or another have traditionally been associated with what is known as "supervised" data processing which emphasizes human selection of training sets for recognition processing. Basically this approach consists of humans trying to find pixels (picture elements) which represent characteristic samples of the spectral reflectance of the objects they wish to identify.

An alternative method of selecting training sets is to use a technique called "clustering" which is known as "unsupervised" recognition processing. Clustering is a multispectral data analysis technique which attempts to identify the inherent patterns of spectral reflectance observed in a given data set. The advantages of this approach are better signature separation, more complete filling of feature space and generally less time spent extracting signatures. Clustering is not a panacea, however, because even though it does identify the basic patterns of spectral reflectance that occur in a scene, these patterns may not be diagnostic of discrete scene classes. What is meant by this is that sometimes two dissimiliar materials, such as algae and trees, may have the same spectral reflectance, and although clustering can isolate this characteristic pattern, the computer cannot tell which material was responsible for producing it, and these two terrain features will be classified.

There are two primary advantages of unsupervised processing which may make it the more desirable approach to use for the application under consideration in this study: First, the amount of supporting field work required in the harsh and remote Alaska coastal environment would be greatly reduced. Secondly, the need for involvement of persons intimately familiar with the sites under study in the signature extracture process would be greatly lessened. Against these factors, however, we have to balance whether the cluster formation algorithms available are sensitive enough to isolate the spectral reflectances of the algal classes it is desirable to map. To assess the performance of clustering we decided to compare recognition results of cluster-generated maps against those produced using training sets picked with the help of extensive ground truth. This was done for two of the three study sites: Zaikof Bay and Cape Yakataga.

In addition to doing "pure" clustering it is also possible, if one is familiar enough with the principles of remote sensing and the target radiation interactions of neutral objects, to combine subjective training set selection with clustering. Using this approach, specialists cross-trained in both biology and remote sensing technology who have never been to the study area may be able to extract as much, if not more, information from a given data set as someone very familiar with the actual site yet only superficially familiar with remote sensing technology. This hypothesis was tested on the Zaikof Bay data set.

Our observations on the time required for implementation and the difficulties associated with each approach were derived from these processing tasks.

2.2 LEVEL II: IDENTIFICATION OF OPTIMUM SPECTRAL BANDS

The concept of a "spectral signature" is based on the observation that many natural materials exhibit a characteristic spectral signal pattern. The sources of this signal pattern are reflected and emitted radiation. Reflected radiation is that component of sunlight reflected by an object to the sensor; it ranges from .33 to 3 μm. Emitted radiation is heat energy and is given off by all objects; it is detectable in the far-infrared part of the spectrum, from 3μm to 30μm. The reflected portion of an object's spectral signature tends to be a more reliable basis for classification than the emitted portion. In large part this is because the processes that control reflection are linked to the basic composition and structure of the object which remains stable. For this reason, we can expect an inherent stability in the pattern of the reflected component of a material's spectral signature. Thus, under variable environmental conditions we would expect to be able to get as good, if not better, classification performance using fewer training sets, all other things being equal, by using only reflected data and avoiding the use of thermal data.

On the other hand, if environmental conditions are stable, the natural temperature variations between natural objects can be just as diagnostic as reflectance differences; for example, sunlight rocks are typically warmer than water and vegetation, and different types of vegetation - because of such factors as canopy structure - also may have characteristic temperatures.

To answer the question of how valuable thermal data is to the mapping of algae along the Alaskan coastline we elected to process a subset of the data in three different ways. First, map a study site using only reflected data, second, make a thermal map of the area and compare results with the reflected data, and finally, if the thermal data appears to add something, make a recognition map based on a combination of reflected and thermal data. The processing we implemented to achieve this objective consisted of:

Reflected Recognition Processing: Zaikof Bay, Latouche Island, Cape Yakataga.

Thermal Level-Slice Maps: Zaikof Bay, Latouche Island

Reflected/Emitted Recognition Processing: Cape Yakataga

2.3 LEVEL III: PROCESSING MODES AND DATA DISPLAYS

In recent years, following the overcoming of the initial obstacles of proving the feasibility of the multispectral scanner and signature recognition concepts as useful resource characterization and mapping tools, the emphasis in remote sensing technology has shifted toward achieving near-real time implementation of the classification process. The prime motivation for this thrust was to take advantage of the high through-put rate of computers thus making it possible to place decision-making information in the hands of managers in a useful time frame. Two concepts in the field of computer-design technology which are influencing how new computers are built and programmed that have emerged as a result of this emphasis are those of making future computers (1) interactive, and (2) user-oriented.

Interactive design characterizes the new third generation of computers. In practice, multiple operators talk via a teletype terminal with the central processing facility which carries on a diaglogue with each of them simultaneously while still dealing with their requests in a time-sharing mode. The result is that everyone feels as if he is personally being taken care of at all times; as soon as a job is completed the operator receives the results and can begin another, permitting many tasks which must be done in sequence to be accomplished in a short time.

In contrast, the older, second generation computers operate in "batch-mode". In batch-mode operators submit jobs in a rigid format on punched cards. When several operators submit jobs at once the jobs are "qued" and processed sequentially by the computer. No one gets any results until all the jobs are finished and listed.

At first blush the special-purpose remote sensing interactive computer appears to be a vast improvement; and in many cases it is, particularly where the jobs to be done are not dependent upon completing a detailed analysis of the results of preceeding jobs before they can be started. The processing of remote sensing data is not as routine as many would like to believe, however, and it may be that batch mode computers are acceptable data processing units. This is important for a user to know, because processing costs are generally lower on these older units and many agencies could afford to make use of a multispectral software processing package stored in a centrally located general purpose computer that serviced other users as well.

We also felt an issue related to the interactive mode of computer processing that was worth examinating was the role of the biologist in data analysis. One school of thought in data processing emphasizes the direct involvement of the user in the data handling stream where this person(s) makes key decisions regarding the fine points of the actual data manipulation. In general this approach has proved successful compared to the early days of remote sensing when engineers with little biological background did most of the processing. Even so, at ERIM we have found that even better results can be obtained in most cases when data processing is conducted by a special type of individual who has been cross-trained at a high level in both remote sensing technology and biology. It may be that there is more to be gained in data processing by having a specially trained person involved rather than an exotic computer.

To provide some insight into this question of what type of individual is most effective at data processing (and thus learn how best the biologist can contribute to effective data processing), we conducted a comparison study. ERIM has both a user-oriented, interactive computer (MIDAS) and a batch mode general purpose computer (IBM 7094). To provide the performance benchmark for the interactive approach we processed one data set on MIDAS with biologists from NOAA's Auke Bay Laboratory who have visited the test sites supervising the processing. The performance benchmark for the batch mode processing under the direction of an ERIM remote sensing specialist/biologist was provided using the 7094 computer.

In our analysis of the results of this comparison we have not attempted to quantitatively prove that one approach is better than the other. Even if we had wanted to do so, the necessary ground truth was not available to us. Rather, what we have attempted to do is illustrate what types of tradeoffs are involved in going either way and what the user will get for the dollar he invests.

The final issue we have addressed in this study is that of optimum data displays. Remote sensing data often appears to the user as a bewildering array of statistics, images and oddly symbolized computer graphics. At ERIM we have made an effort to structure our software and output products into user-oriented formats that will improve communication, understanding and utility. Because these might go unnoticed without a basis for comparison, we have chosen to call them out and briefly describe them as representative of desirable elements of any operational remote sensing system that might be specified for intertidal analysis. In particular, the reader should note our use of EPLOT's and the ink-jet printer displays used to produce the color-coded recognition maps.

2.4 ORGANIZATION OF REPORT

An unusual feature of the work done for this project is that several of the individual data processing tasks, which make up the entire data processing effort, support more than one of the project's analysis programs. This poses a problem in report writing, because for logical presentation each analysis program should be described completely - beginning with data collection moving through data processing, continuing with analysis and finishing up with conclusions. Needless to say, for this project a report following these guidelines would consist largely of repetitions of data processing descriptions. To avoid such needless repetition, we have instead adopted the following plan: chapters 3.0 and 4.0, which deal with the technical details of data collection and data processing respectively, are organized in order of the chronological occurrence of the steps involved in the generation of the products. This makes it possible to present a complete and easy to follow discussion of the sequence of data handling associated with each data set. Chapters 5.0 and 6.0, which contain respectively the results and discussion and conclusions, are instead organized along the lines of the analyses programs, and as a result jump around somewhat in their treatment of the data sets as different questions related to the most feasible method of obtaining the desired results are addressed.

Thus, those readers primarily interested in getting a quick picture of what we learned as a result of this study should concentrate on Chapter 5.0 and 6.0. On the other hand, readers more interested in the technical aspects of data collection and manipulation will find their interests addressed in Chapters 3.0 and 4.0.

3.0
AIRBORNE DATA COLLECTION AND DATA QUALITY

Acquisition of the airborne data used in this study took place on 27 and 28 June, 1976. Zaikof Bay and Latouche Island were overflown on the 27th and Cape Yakataga was covered on the 28th. The base of operation for the aircraft was Cordova, Alaska.

3.1 TIMING OF OVERFLIGHT

Data collection was achieved at all three sites within 1/2 hour of the occurrence of low tide and maximum sunlight on these dates. Tidal height was -1.9 ft. This is 1.4 ft. less than the yearly maximum low tide of -3.3 ft. which occurred approximately two weeks earlier. Scheduling data collection for such a combination of low tide and maximum sunlight hypothetically optimizes data collection by measuring the greatest exposure of the intertidal zone and the best illumination conditions.

3.2 ENVIRONMENTAL CONDITIONS

In spite of the considerable amount of advance planning by all parties concerned to insure an optimal data set, the environmental conditions that prevailed at the tidal low during the period for which the aircraft was available were for from optimum. Sky conditions on the 27th of June were dark and overcast at both Zaikof Bay and Latouche Island. On the following day the overcast was not as heavy as Cape Yakataga and some thin spots in the cloud cover improved illumination.

The effect of the poor illumination experienced at all three sites on data quality was to lower the signal-to-noise ratio. In effect, we are now dealing with a worst case situation instead of an optimum data set. Thus, the results of this project should be considered as a baseline for the worst performance that can be expected from an airborne multispectral mapping system, and that under better illumination conditions performance will be better.

A consequence of not collecting the data at maximum annual low tide is that there were considerable areas of wet sand and rock and tidepools at all three test sites which had appeared dry during the ground truthing activities that took place two weeks earlier. Since the presence of a layer of water over a material can significantly alter that material's spectral signature this condition caused problems in the classification of materials so affected. For a further discussion of the affects of this situation, see the discussion of the Zaikof Bay test site results in Chapter 4. Its implications are dealt with in Chapter 5.

3.3 SENSOR CONFIGURATION

Because of prior committments, ERIM's own airborne multispectral data collection system, consisting of a C-47 aircraft and the M-7 scanner, were not available for this project. Instead, a Bendix M2S scanner installed in a Cessna 310 owned by Walker Associates of Seattle, Washington was used.

The M2S scanner is a 12-channel system and 11 of the 12 channels were used to collect data in this project. The 12th channel was used to store electronic "housekeeping" data. The channel numbers and their associated bandpasses are listed in Table 1. The Instantaneous Field of View (IFOV) of the M2S is 2.5 milliradians, which means that at an altitude of 1000 feet above terrain the minimum area over which the scanner integrates received radiation is 2.5 ft. on a side, or 6.25 sq. ft. This, in effect, becomes the smallest size object that could be resolved.

3.4 DATA PRODUCTS

Five passes were flown over each test site at different altitudes and with varying combinations. The five combinations considered were:

1) a pass at 1000ft. AGL parallel to the shoreline.
2) a pass at 1500ft. AGL parallel to the shoreline.

TABLE 1. MULTISPECTRAL SCANNER CONFIGURATION FOR ALASKAN INTERTIDAL ZONE DATA COLLECTION, 26 and 27 June, 1976.

Channel		Spectral Band ($\lambda_1-\lambda_2$) (in μm)	Peak Wavelength(λ_c) (in μm)
1	Violet:	0.350 - 0.470	0.410
2	Blue:	0.415 - 0.515	0.465
3	Blue-green:	0.475 - 0.555	0.515
4	Green:	0.520 - 0.600	0.560
5	Yellow:	0.540 - 0.640	0.600
6	Orange:	0.600 - 0.680	0.640
7	Red:	0.640 - 0.720	0.680
8	NIR-1	0.680 - 0.760	0.720
9	NIR-2	0.725 - 0.905	0.815
10	NIR-3	0.925 - 1.105	1.015
11	thermal	8.000 -14.00	11.00
12		"Housekeeping Data"	*

3) a pass at 1000ft. AGL perpendicular to the shoreline.
4) a pass at 500 ft. AGL parallel to the shoreline.
5) a pass at 1000ft. parallel to the shoreline, but with the mirror rate reduced by a third.

For each pass, the scanner data was collected and stored on a high density digital tape (HDDT).

In addition to the MSS data, high resolution vertical aerial photography was collected using a 70mm Hasselblad camera and SO-397 ektachrome EF natural color film. Normally the camera was operated during pass one.

A complete flight log and the rationale for the different pass combinations is available in the companion study for this report (Polcyn et.al., 1977).

3.5 DATA QUALITY

Prior to beginning data processing a data quality check was performed. The purpose of this check was twofold. First, it provided insight into how the poor illumination conditions that existed during data collection affected the signal-to-noise ratio of the specific data sets to be processed. Secondly, it permitted us to find out if there had been any equipment malfunctions resulting in exceptionally poor quality data being recorded for a particular spectral band. The elimination of a channel with very poor data prior to recognition processing is desirable because the addition of noise to training sets seriously compromises the ability of the classifier to recognize what may be important spectral differences between materials.

The procedure used for analyzing data quality in this study involved assessments of both the dynamic range and noise properties of each spectral band. As defined for our purposes, dynamic range was the range of integers over which the data values representative of the variability to be encountered over the whole scene (data set) are distributed. This range was determined by histogramming a systematic 4% sample of the data values in each spectral band for a given data set.

When applied to the Cape Yakataga Data Set (Run 21) this procedure yielded the information shown in Table 2. Dynamic range varied significantly between channels, being as low as 33 integer values in channel 8 and as large as 222 in channel 2.

A measure of "system noise" was obtained from the standard deviation of a spectral signature extracted from a water area of uniform appearance and temperature. The resulting rms fluctuations observed in the signal level for each channel are listed in column 4.

By dividing the dynamic range for each channel (column 3) by the corresponding rms noise fluctuation (column 4), a ratio of signal-to-noise (S/N) for the MSS system used in this study was calculated (column 5). This quantity indicates the number of quantum contrast levels available in each channel and provides a relative means of ranking channels according to their ability to distinguish between objects of different reflectivity. The figures in column 5 show one channel with (relatively speaking)a very good S/N ratio, five channels with generally better S/N ratios, and five channels with generally poorer S/N ratios. This relationship is diagrammed in Figure 3. Fortunately, all three important spectral categories of radiation (near-infrared, visible and thermal) are represented in two visible channels, the thermal channel, another visible channel, and finally another near-infrared channel.

Only channel one (channel 1) had a S/N ratio so poor we felt it should be excluded from further consideration. Thus, all further processing of the Cape Yakataga data set was carried out using only channels 2-11.

It also appears that the illumination conditions that prevailed at Cape Yakataga during data collection did not greatly affect data quality in an adverse fashion. This conclusion is based on a comparison of the S/N ratios observed for the Cape Yakataga data with those obtained using the same type of scanner to collect data on a bright, sunny day over a

TABLE 2. DATA QUALITY FOR CAPE YAKATAGA (RUN 21)

1	2	3	4	5	6
Sensor(tape) channel	Spectral Band μm (50% response points)	Dynamic Range* (data values)	Noise (RMS signal fluctuations for a uniform target)	Signal to Noise Ratio	Data Quality Ranking
1	Violet 0.350-0.470	0-85/86	8.60	9.9	11
2	Blue 0.415-0.515	34-255/222	8.27	26.84	9
3	Blue-green 0.475-0.555	35-166/132	3.73	35.39	7
4	Green 0.520-0.600	32-112/81	1.89	42.86	5
5	Yellow 0.540-0.640	25-79/55	1.09	50.46	2
6	Orange 0.600-0.680	25-67/43	0.86	50.00	3
7	Red 0.640-0.720	25-61/37	1.25	29.60	8
8	NIR-1 0.680-0.760	26-58/33	0.78	42.31	6
9	NIR-2 0.725-0.905	18-91/74	1.07	69.16	1
10	NIR-3 0.925-1.105	17-83/67	2.97	22.56	10
11	Thermal 8.00-13.0	49-102/54	1.16	46.55	4

*Range over which 96% of the pixels are distributed

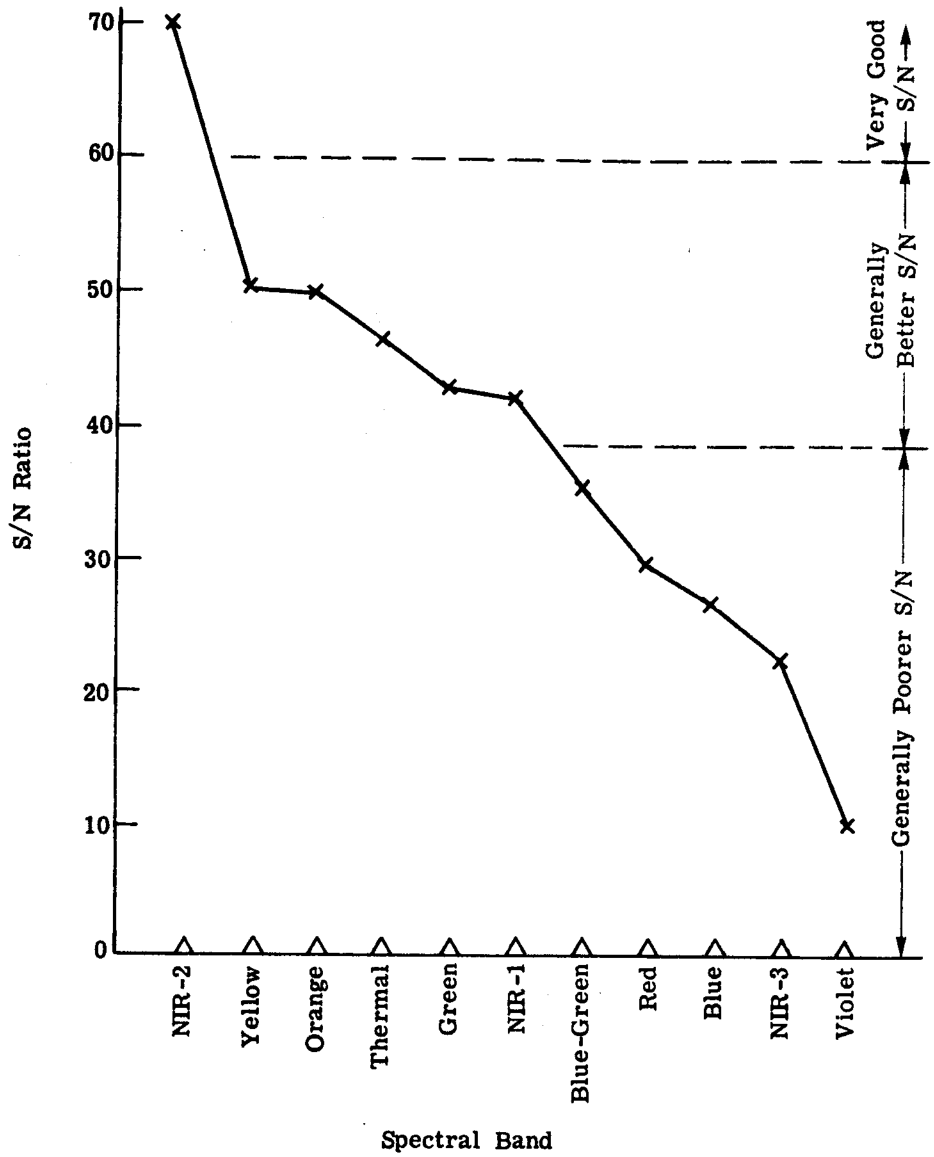


FIGURE 3. SIGNAL-TO-NOISE RATIOS FOR CAPE YAKATAGA (RUN 21) DATA SET.

Texas forestry study site (Sadowski and Sarno, 1976). The S/N ratios obtained for the two data sets are basically similar.

3.6 SCAN ANGLE EFFECT ANALYSIS

Because aircraft multispectral scanners are capable of collecting data over a large range of view angles ($\pm$ 60° from nadir in the case of the M2S scanner), scene radiance values as recorded by the detectors can include a systematic variation associated with the scan angle. This variation is typically due to the scattering and attenuating influences of the atmosphere as path length from sensor to ground varies with scan angle (Turner, 1974). The bidirectional reflectance properties of the objects in the scene are another major cause (Suits, 1972).

To determine the magnitude of scan angle effects in the Yakataga data set an average scan line was computed for the end of the run over a uniform area of water. The average scan line contained average signal values for 70 divisions across the scene, each of which had been calculated by averaging 10 adjacent resolution elements over 51 successive scan lines. The effect of averaging 510 resolution elements into each of the divisions in effect smooths out any high frequency variations associated with system noise in order that gross radiance changes associated with scan angle can be observed more clearly.

Figure 4 shows the shape of the average scan line computed for three of the 10 channels considered. The portion of the scene included in the calculations is just off the tip of Cape Yakataga at the end of Run 21. This area was selected because at this point the scene is composed entirely of a single material -- water. It is desirable to make such calculations over uniform areas to reduce the possibility of signal variances being due to the intrinsic reflectional differences between different materials and not scan angle, in which we are interested.

It is evident from inspection of the curves that scan angle effects do occur in this data set at both ends of the scan line, at less than point 50 and beyond point 600. The explanation for the asymmetrical

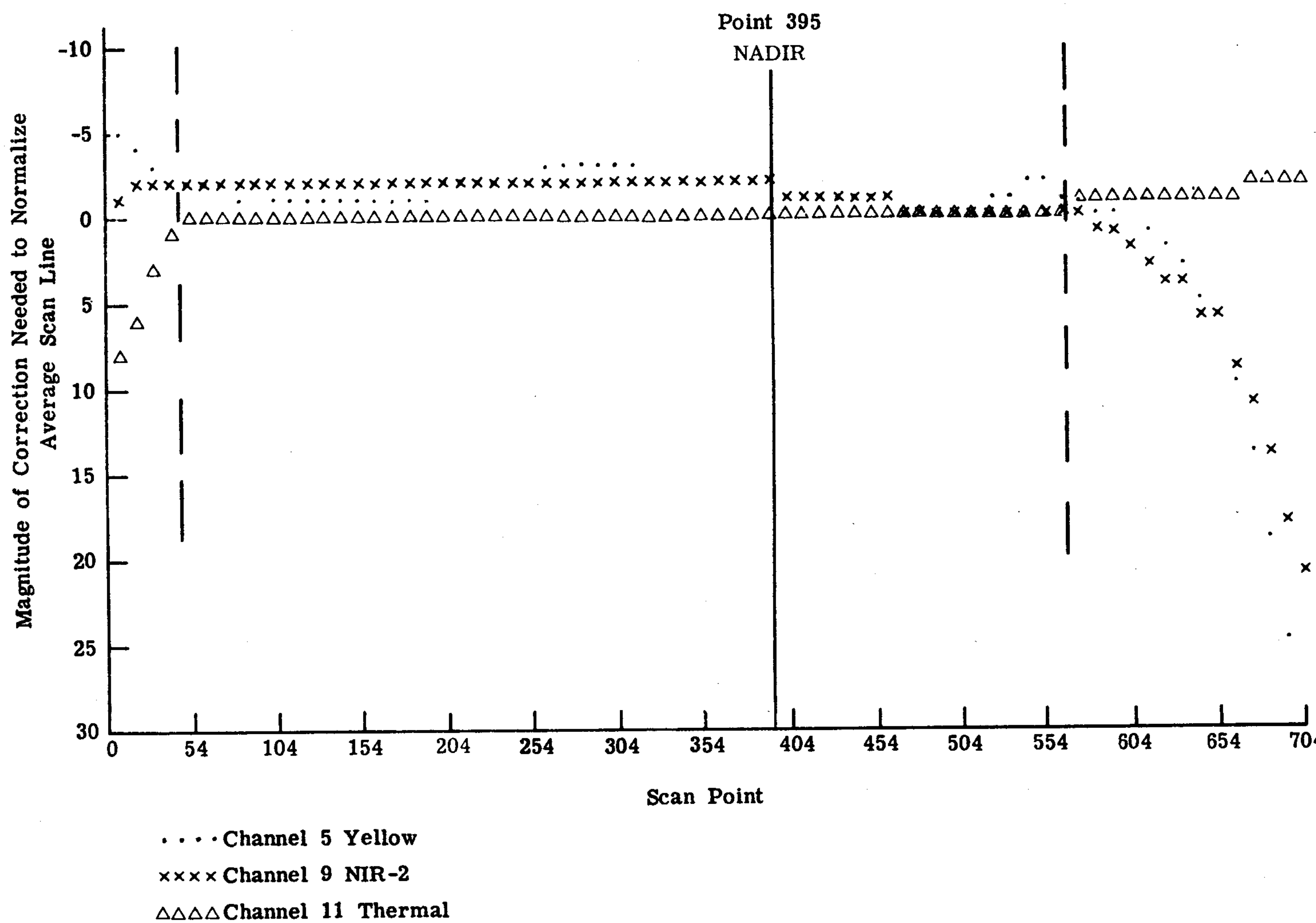
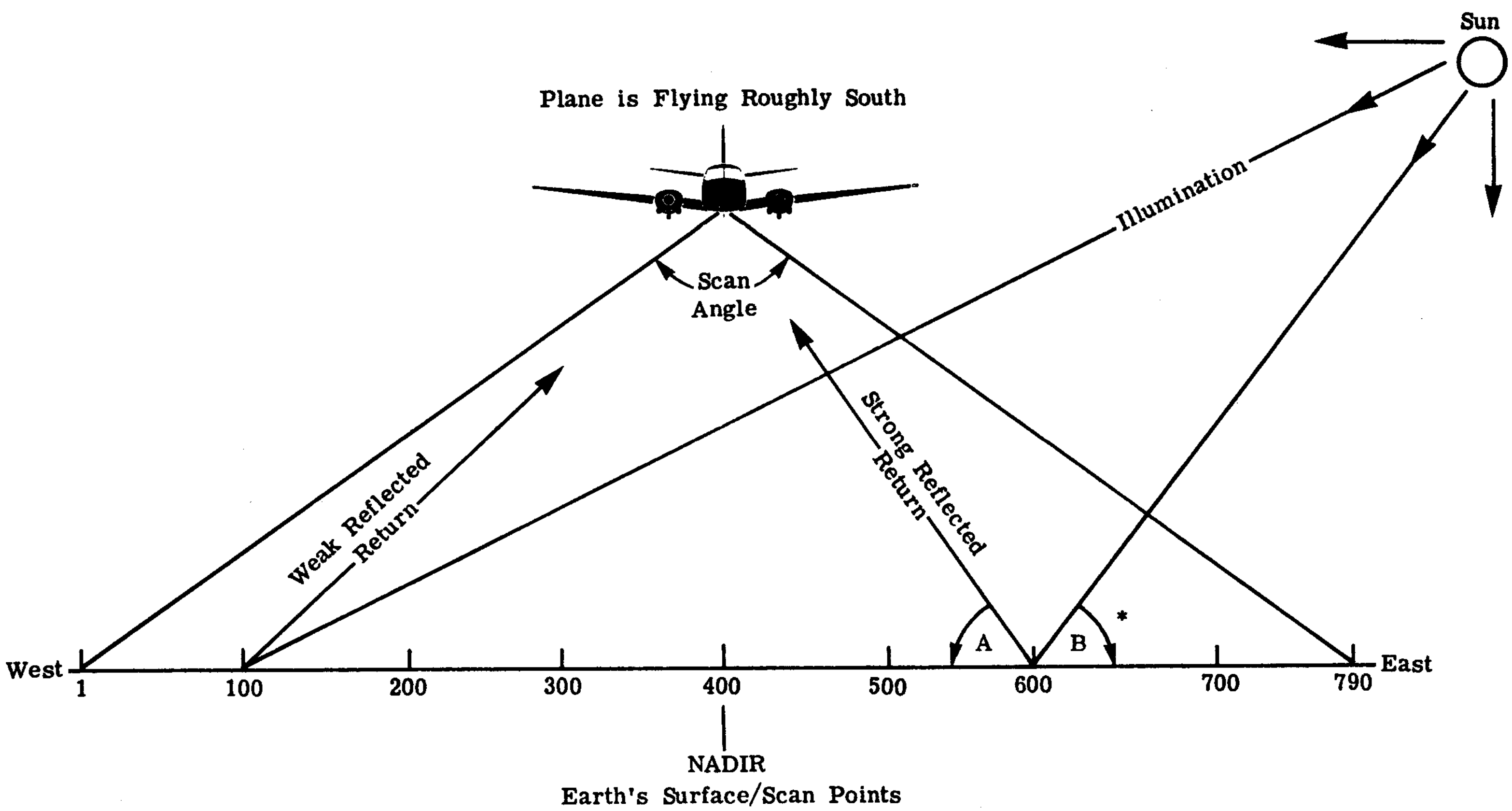


FIGURE 4. SHAPE OF THE AVERAGE SCAN LINE OVER WATER FOR SELECTED CHANNELS.

slope of the curves about the nadir point most likely has to do with the location of the sun's position relative to the sensor. Since the data were collected early in the morning, on one side of the scanline the sun's illumination comes from behind the sensor, while on the other side illumination is toward the sensor, as shown in Figure 5. This would account for what appears to be specular reflection from the water in channels 5 and 9 beyond point 600, on the west side of the run. The thermal channel shows a strong angle effect on the east side of the scan line, which may indicate the presence of a cooler current in this area.

If one wished to a priori minimize the possibility of sun angle effects in multispectral data, it is possible to do so by orienting the flight line either directly toward or away from the sun. This has the effect of making the entire scan line perpendicular to the direction of illumination. Any radiance variations that do occur will then be symmetrical, and if they are large enough to need to be removed a simple parobolic function can be used to correct the data.

For the Cape Yakataga data set we did not feel that it was necessary to correct the data beyond avoiding the edges of the scan lines. Thus, in subsequent recognition processing of this data set we concentrated on the scene area between points 60 and beyond 600. The procedures involved in the recognition processing of data for all three study sets is discussed in the next chapter.



*Where ∠A=∠B Specular Reflectance Will Result from Calm Water

FIGURE 5. DIAGRAM OF SUN-SENSOR GEOMETRY FOR CAPE YAKATAGA DATA SET.

4.0

COMPUTER DATA PROCESSING

There are three logical ways in which the computer work for this project can be described: first, on the basis of chronology; second, on the basis of processing techniques used; and third, on the basis of study sites. Of these three approaches the first, chronology, is of least significance technically, but should be included to show how the project progressed and at what stage different individuals were involved. It will be dispensed with briefly at the end of the introductory material to the present chapter. Between the remaining two approaches we have chosen to use thestudy sites as the basic framework around which to organize our discussion, treating the specific data processing techniques applied to the different data sets as the subheadings. The advantage of this organization is that comparison of the results produced by the different techniques can be discussed sequentially with regard to the same data set. This makes it possible to avoid the "apples and oranges" confusion that might result if we tried to compare the results of two processing techniques applied to different study sites. A summary of the processing and results that are discussed in this chapter is contained in Figure 6 which also serves as a useful overview of the material that will be covered.

Returning now to the chronology of the project, the sequence of events associated with this project and the principal participants are outlined below:

When	What	Where	Who
early June, 1976	Ground truth collection	Study Sites, Alaska	Zimmerman, Gnagy et al
late June, 1976	Airborne data collection	Study Sites, Alaska	Polcyn, Stewart

	ZAIKOF BAY	LATOUCHE POINT	CAPE YAKATAGA
I. SUPERVISED RECOGNITION PROCESSING			
A. REFLECTED RADIATION STUDIES			
1. 9 channels/no ground truth/7094 computer*	X	X	X
2. 4 channels/interactive mode/MIDAS computer°	X	X	X
B. THERMAL RADIATION STUDY	X	X	
II. UNSUPERVISED RECOGNITION PROCESSING			
A. REFLECTED RADIATION STUDY°	X		
B. REFLECTED AND THERMAL STUDY°			X

*indicates phase I processing: June, 1976-March 1977

°indicates phase II processing: April 1977-December 1977

Figure 6 . Summary of Computer Data Processing Accomplished for each study site.

August, 1977	Phase I processing; Supervised, reflected radiation 9 channel, 7094 maps	ERIM, Ann Arbor	Lyzenga, Marinello
September, 1977	Phase I results sent to Sponsor for analysis	Alaska	Bruce, Zimmerman
April, 1977	Interim Report, describing Phase I progress	ERIM, Ann Arbor	Polcyn, Lyzenga
August, 1977	Beginning of Phase II processing; Supervised 4 channel, interactive mode/MIDAS maps	ERIM, Ann Arbor	Zimmerman, Gnagy, Roller, Marinello
September, 1977	Paper given at Symposium		Zimmerman, Gnagy
October, 1977	Completion of Phase II Processing: Supervised thermal maps, and unsupervised reflected and reflected and thermal 4 channel, 7094 maps	ERIM, Ann Arbor	Roller
December, 1977	Writing of Final Report	ERIM, Ann Arbor	Roller, Polcyn

Before beginning the discussion of the specific data processing for the first study site, a brief description will be given of the preliminary data reformatting steps involved in getting the data ready to process. These steps were common to all three study sites. By discussing them here we can avoid repeating the description of reformatting as each of three study sites in turn is discussed.

The data collected by the scanner is recorded in the aircraft in high density digital form on a magnetic tape (HDDT). The HDDT must then be converted into a computer compatible tape (CCT). Once a CCT is produced it must then be reformatted into a form that is acceptable by the software that is being used to analyze the data. The 7-track ERIM format CCT's used for this project were prepared using the University of Michigan's Amdahl 470 computer facility. A total of nine data sets were converted: four over Zaikof Bay (Runs 4-7); three over Latouche Point (Runs 9, 10, and 12); one over Cape Yakataga (Run 21); and, one of the calibration panels at Cordova Airfield (Run 15). In the rest of this chapter the specific processing techniques are described that were applied to the data sets for each study site.

4.1 ZAIKOF BAY

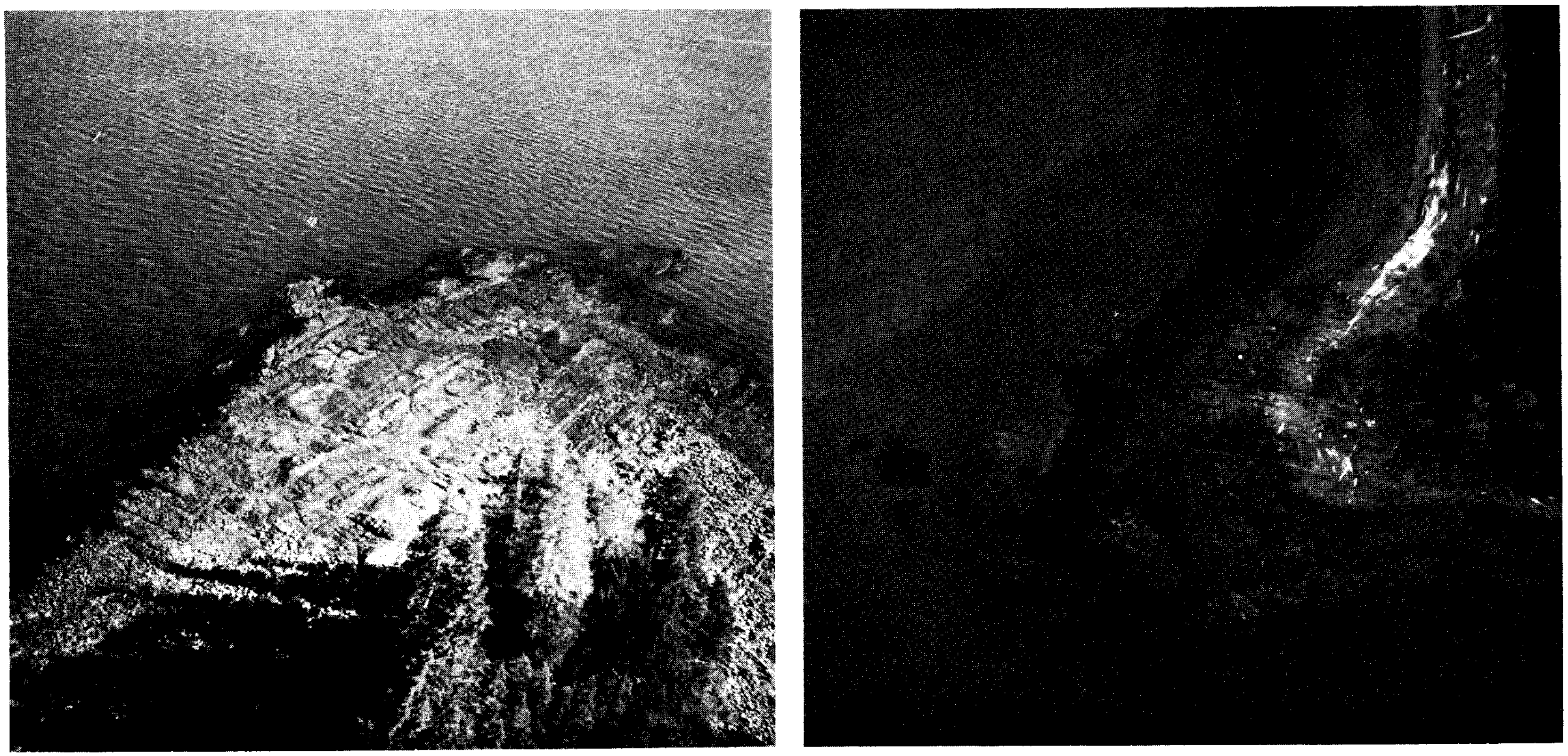
All of the processing for the Zaikof Bay study site was performed using data collected during Run 7. Run 7 was the low altitude run (400 ft AGL) flown parallel to the shoreline. Two airphotos of the study site are shown in Figure 7.

4.1.1 SUPERVISED RECOGNITION PROCESSING

Three kinds of supervised recognition processing were applied to Run 7 data. The first kind of recognition processing was done during Phase I. It was accomplished using nine channels of reflected radiation and the 7094 computer by ERIM analysts using just the air photos to guide training set selection (no ground truth). The second kind of supervised processing of Zaikof Bay data was accomplished in Phase II. Here NOAA Auke Bay Fisheries Laboratory personnel helped prepare recognition maps in an interactive mode using the MIDAS computer and four channels of reflected radiation. The third kind of supervised processing involved analyzing the information content of the thermal band and consisted of level-slicing techniques.

4.1.1.1 REFLECTED RADIATION STUDIES

In Phase I and the interactive mode processing of Phase II, it was decided not to include the thermal channel in the



a. Low-Oblique photo taken 14 June 1976

b. Vertical photo taken 27 June 1976

FIGURE 7. AIR PHOTOS OF ZAIKOF BAY STUDY SITE

recognition processing. The reason for this decision was that thermal data is closely coupled to ambient environmental conditions, and the results obtained using it -- either good or bad -- might not be representative of what can be done under normal conditions or repeatable. Results based on reflected radiation would represent a measure of performance based on the fundamental properties of the materials imaged, and hence should be repeatable and serve as a useful, conservative guide to the specification of an operational survey system.

In the first reflected radiation study all nine channels of useful visible and near-infrared data were processed using the 7094 computer. In the second study the four channels that were found best (i.e., those channels that were most valuable for spectrally discriminating between training sets) in study one were used. The second study was limited to four channels because it was done on the MIDAS computer whose classifier was designed to accept no more than four channels of input data. For Landsat data analysis and most aircraft multispectral data processing this now has been shown to be adequate.

Study 1: Nine Channels of Reflected Radiation/No Ground Truth/ 7094 Computer

The selection of training sets for this study was made by ERIM analysts from air photos of the study site annotated by Dr. Zimmerman, who headed the ground truth effort. Line and point numbers for each training set were obtained from training sets drawn on graymaps of channel 9 (NIR-2). Training set locations were determined by first roughly localizing them on the graymap using the annotated photography and then fine "tuning" the location of their boundaries by matching them up with zones of contrast observable in the graymap. In this way training sets were established for five types of material, including algae, rock, water, grass and trees. For algae, six training sets in all were used.

Classification of the data was performed on the 7094 computer using all nine available visible and near-infrared spectral bands. The recognition results are shown in the map in Figure 8.

This map was sent to Dr. Zimmerman for evaluation in September, 1976.

Study 2: Four Channel/Interactive Mode/MIDAS Computer

In August, 1977 Dr. Zimmerman and Mrs. Gnagy visited the ERIM facility in Ann Arbor to learn more about digital computer data processing techniques as applied to multispectral remote sensing data. While they were here they assisted in actual data processing on the MIDAS computer.

The MIDAS computer is designed for interactive data processing, in which the computer prompts the operator with several alternatives and the operator then chooses what he wishes to do, with the option to repeat a step until he is satisfied with the results.

In the Phase I processing we felt our most serious limitation was inadequate knowledge of the study site which made training set selection difficult and potentially inaccurate. For example, the ERIM analysts were able to identify seven distinct contrast zones where we knew algae occurred, but Dr. Zimmerman later informed us he felt only four basic species associations were present. Presumably, we were mistaking horizontal vegetation density classes with the species associations for additional types.

To avoid misplacing training sets and take advantage of Dr. Zimmerman's first-hand knowledge of the study, it was decided that he should pick the training sets. This was done in the following manner: A single band image similar to a graymap was produced on a television monitor screen that is part of MIDAS. A cursor was then moved to points which were used to designate the corners of a polygon which enclosed the area to be used as a training set. As the corners were identified, the computer automatically drew in the connecting side of the polygon. When the polygon was completed the training set characterization statistics used in the classification process were generated. These statistics include the mean and standard deviation for each channel.

FIGURE 8. LEGEND

algae	light red olive brown dark green light green orange light purple	rock	dark grey black	grass: yellow trees: light orange water: blue unclassified: white

Scene: 1,554, 1, 1, 790, L

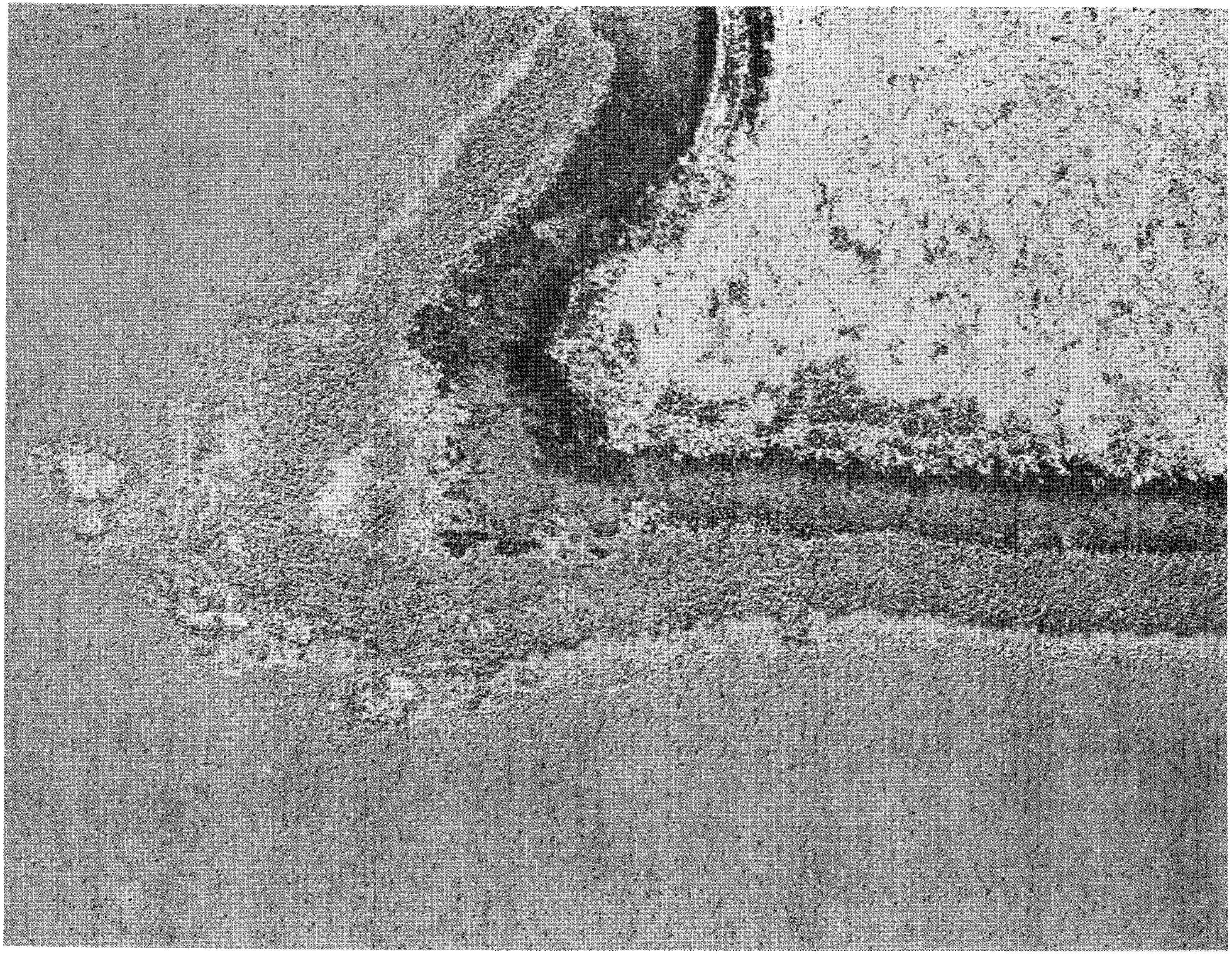


FIGURE 8. SUPERVISED RECOGNITION MAP OF ZAIKOF BAY: 9 CHANNELS OF REFLECTED RADIATION/NO GROUND TRUTH/7094 COMPUTER

Upon completion of training set selection, the data was immediately classified. The MIDAS recognition processor uses the maximum-likelihood decision rule with a priori probabilities. Use of this rule assumes the things you want to recognize are characterized by multi-model Guassian multivariate distributions. The variables in this case being the different signal levels in the various spectral bands.

As indicated in the title of this sub-section, only four channels of data were used. The reason for this is that the classifier of MIDAS was only designed to handle a maximum of four input channels. Thus, we had to select only four channels for further processing from the nine used in the preceeding study.

To make this selection we used the results of the Phase I processing to guide our choice. We did this by using the statistics of the training sets selected in Phase I as input to a computer program called ALCHAN. ALCHAN was written to statistically find the best subset of channels by searching through all possible subsets. "Best" in this case means minimizing an average pairwise linear approximation of the probability of misclassification.

ALCHAN was run three times using the three sets of Phase I signatures from the three study sites. The results are listed in Table 3.

TABLE 3

FOUR CHANNEL SUBSET SELECTION FOR
SUPERVISED PROCESSING BY STUDY SITE

Study Site	Best Combination of Channels
1. Zaikof Bay	9, 8, 4, 6
2. Latouche Point	9, 4, 8, 10
3. Cape Yakataga	9, 5, 8, 4

Channels 9, 8, and 4 were unanimously selected on the basis of all three study sites. For the fourth channel, a three way tie existed between channels 6, 10, and 5. Channel 5 was ultimately selected because it placed higher in usefulness (second in contrast to fourth for channels

6 and 10) and it had a better signal-to-noise ratio. Thus, for all four channel processing except the unsupervised work the input data was:

TABLE 4

SUBSET OF CHANNELS SELECTED FOR
PHASE II REFLECTED RADIATION STUDIES

Channel	Spectral Band	
9	0.725-0.905	NIR-2
8	0.680-0.760	NIR-1
5	0.540-0.640	yellow
4	0.520-0.600	green

Dr. Zimmerman selected seven training sets and then the data set was classified. The results are shown in the recognition map in Figure 9. A copy of this map accompanied Dr. Zimmerman when he left Ann Arbor.

4.1.1.2 THERMAL RECOGNITION STUDY

Chronologically, this study was carried out <u>after</u> the unsupervised recognition processing of the Zaikof Bay data set described next. Yet, because the technique used is a supervised one, it is included here. The technique is a simple one and it is called level-slicing. It consists of color coding ranges of values in a single channel of data to make a map-like image.

In the case of the thermal band we examined the spatial distribution of pixels with the same temperature and were able to construct the map shown in Figure 10 by grouping together objects with similar temperatures. Although boundaries between some scene classes are not as clear as in the proceeding maps, one thing that stands out totally unambiguously in this map is the zone of rock rubble that occurs between the shoreline and the vegetated uplands.

FIGURE 9. LEGEND

Algae

alario:	red	water:	blue
ulva:	green	rock:	black
Fucus:	gold	trees:	yellow
Mixed:	orange	unclassified:	white

Scene: 1,550,1,1,790,1

FIGURE 9. SUPERVISED RECOGNITION MAP OF ZAIKOF BAY: FOUR CHANNELS OF REFLECTED RADIATION/INTERACTIVE MODE/MIDAS COMPUTER.

LEGEND

Very cool:	blue	warm:	green
cool:	yellow	Very warm:	red

Scene: 1,400,1,1,790,1

FIGURE 10. THERMAL CONTOURING OF ZAIKOF BAY

4.1.2 UNSUPERVISED PROCESSING: FOUR CHANNELS OF REFLECTED RADIATION 7094 COMPUTER

This study actually took place in parallel with the interactive mode processing involving Dr. Zimmerman and the MIDAS computer. Its purpose was to provide a comparison of unsupervised and supervised techniques on the same data set. Training sets for the unsupervised recognition processing were obtained by "clustering". A brief description of clustering is contained in Section 2.1.

The clustering algorithm identified 35 unique spectral signatures. Using these signatures the data was then classified using the 7094 computer.

Before a map could be produced, however, it was necessary to color code the clusters. To aid in properly assigning colors to clusters we analyzed EPLOTS and video displays of the candidate color combinations on the MIDAS video display unit. EPLOT's are a two dimensional representation of the chi-square distribution of the training set signatures. The EPLOT for the Zaikof Bay clustering output is shown in Figure 11. The colors by which the clusters in the EPLOT are coded correspond to the colors assigned to the pixels classified as belonging to that cluster in the recognition map output.

The recognition map itself is shown in Figure 12. In many ways this map appears to be the best overall representation of the Zaikof Bay study site. The implications of this will be dealt with in Chapter 5.0. We now turn to the processing of the Latouche Point data set.

4.2 LATOUCHE POINT

The processing for the Latouche Point study site was performed on the data collected during Run 9. Run 9 was made at 1,000 ft AGL parallel to the beach. A vertical airphoto of the study site is shown in Figure 13.

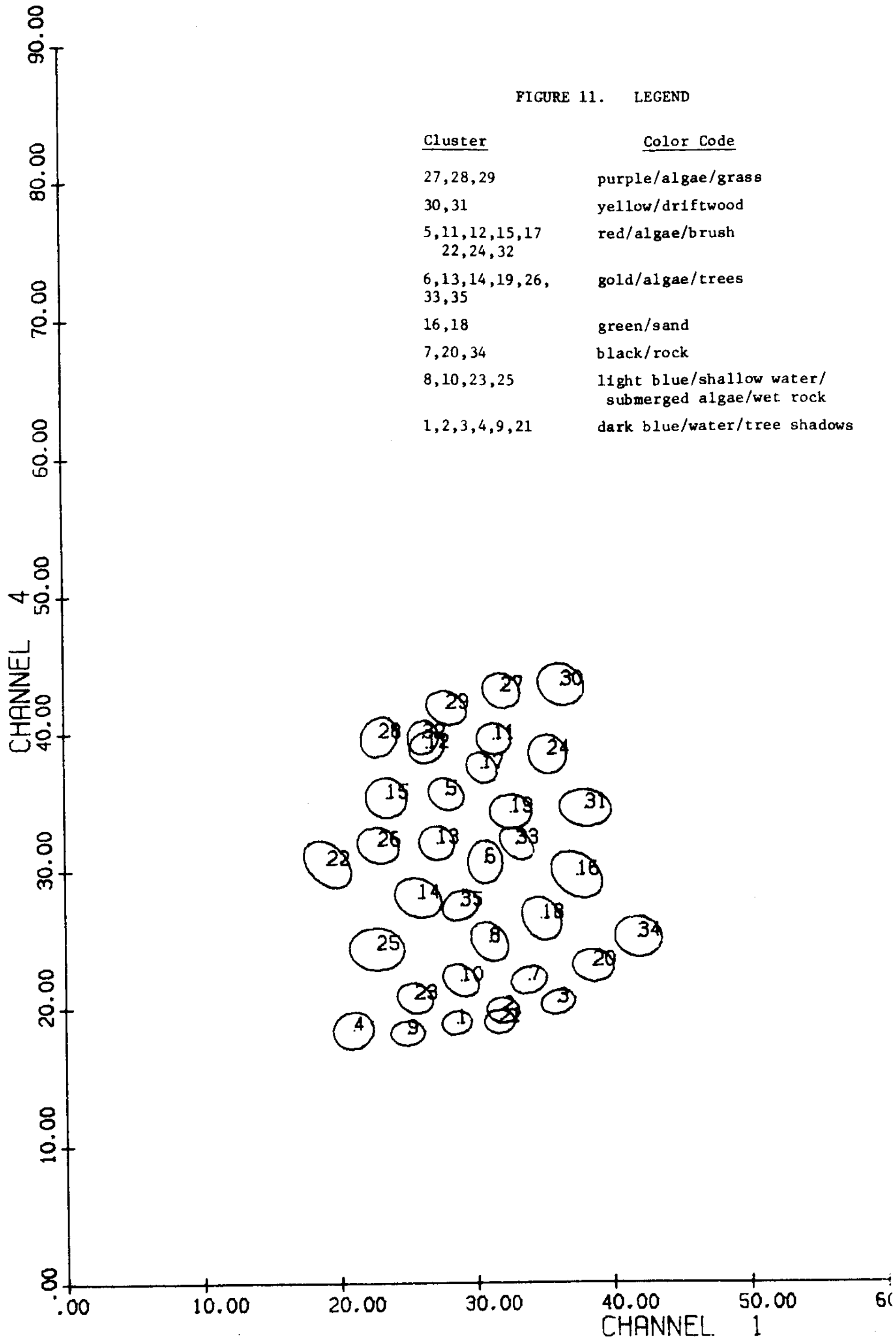
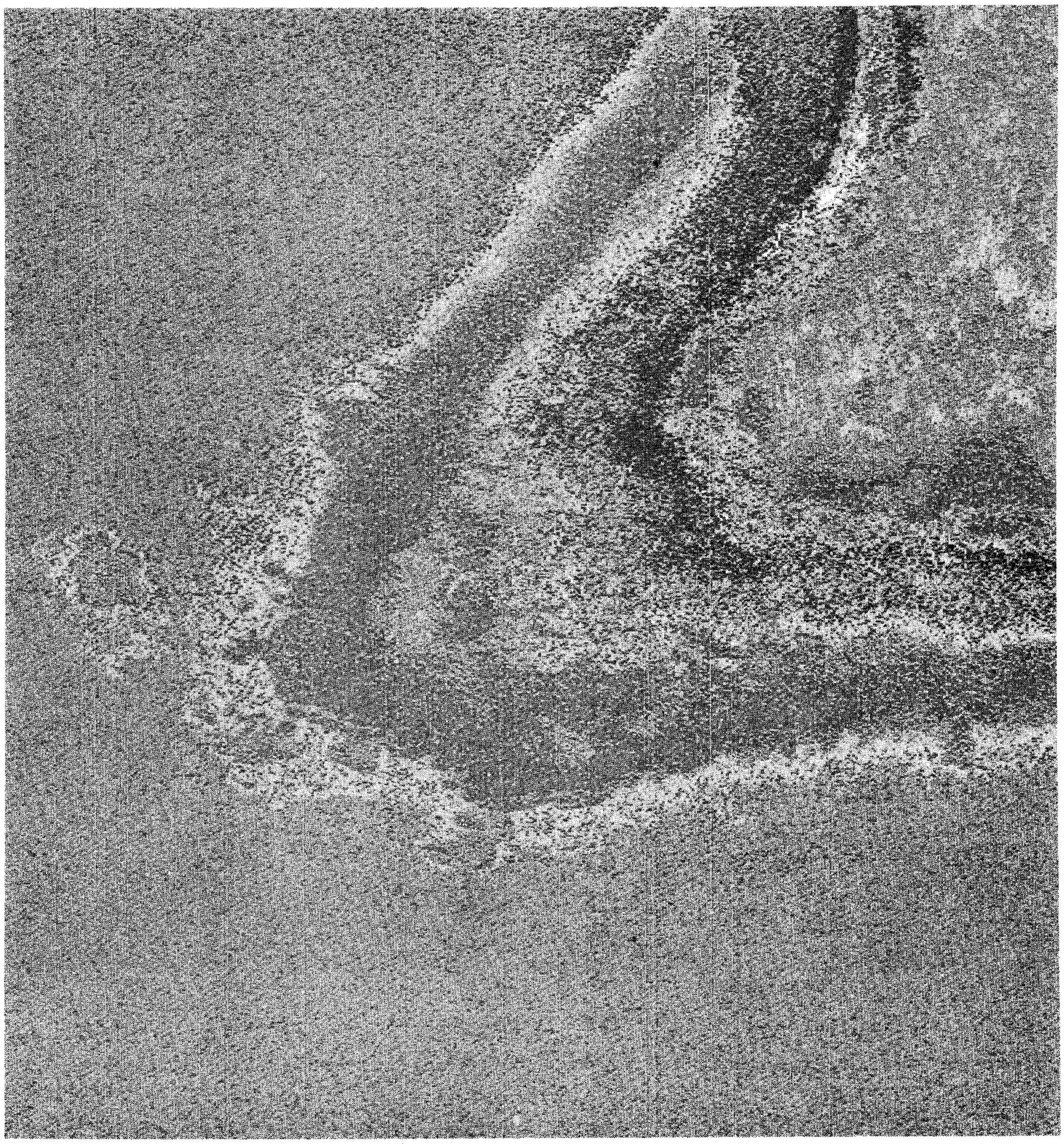


FIGURE 11. LEGEND

Cluster	Color Code
27,28,29	purple/algae/grass
30,31	yellow/driftwood
5,11,12,15,17 22,24,32	red/algae/brush
6,13,14,19,26, 33,35	gold/algae/trees
16,18	green/sand
7,20,34	black/rock
8,10,23,25	light blue/shallow water/ submerged algae/wet rock
1,2,3,4,9,21	dark blue/water/tree shadows

FIGURE 11. EPLOT OF CLUSTERING-DERIVED TRAINING SETS USED IN UNSUPERVISED RECOGNITION PROCESSING OF THE ZAIKOF BAY DATA SET.



LEGEND

water/tree shadows
shallow-water/submegent algae/wet rock: light blue
algae/trees: gold
algae/bush/red
algae/grass/purple
sand: green
rock: black
driftwood: yellow and white

Scene 1,400,1,1,790,1

FIGURE 12. UNSUPERVISED RECOGNITION MAP OF ZAIKOF BAY: FOUR CHANNELS OF REFLECTED RADIATION/CLUSTERING/7094 COMPUTER

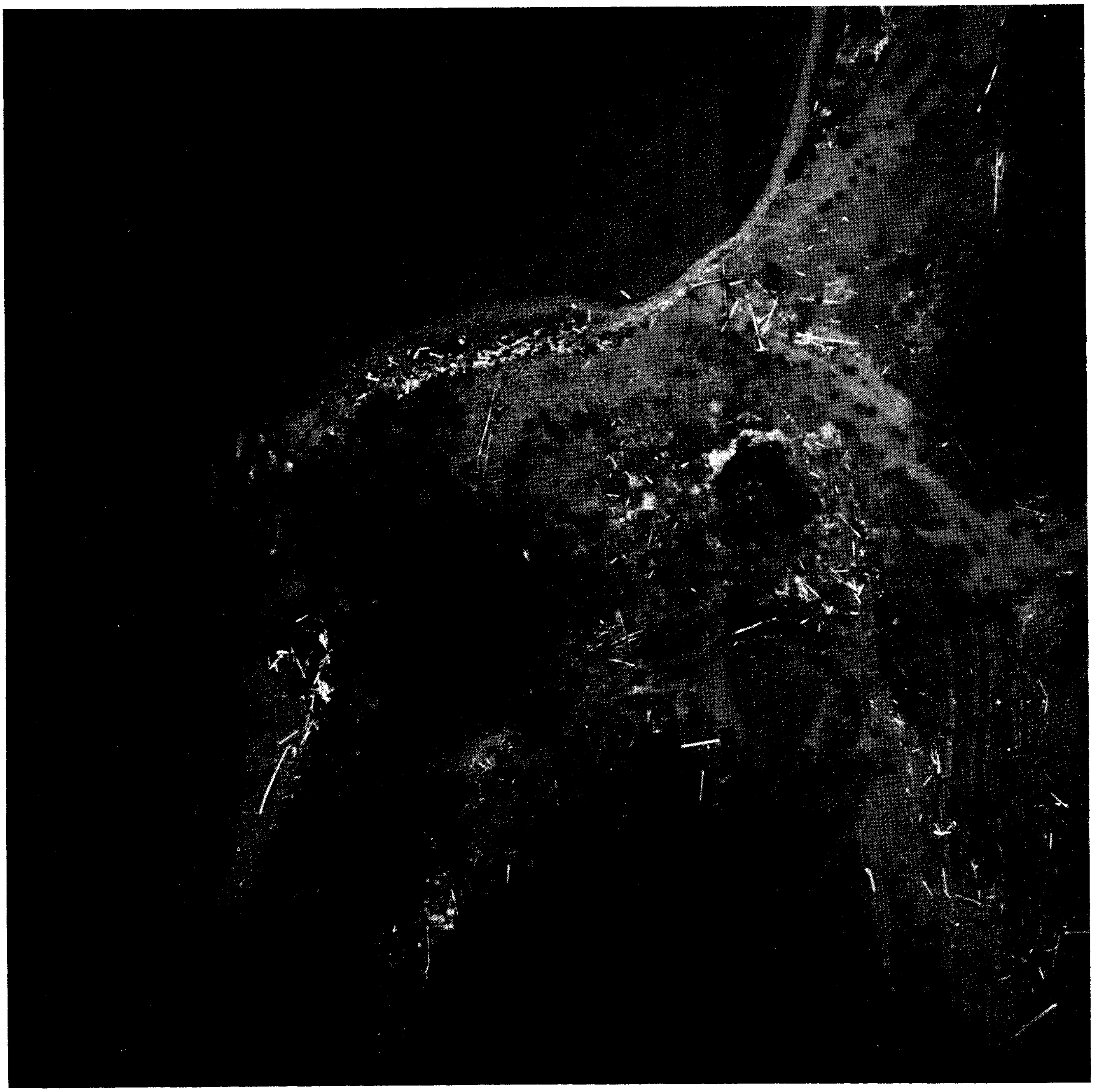


FIGURE 13. VERTICAL AERIAL PHOTOGRAPH OF LATOUCHE ISLAND STUDY SITE COLLECTED 27 JUNE 1976.

4.2.1 REFLECTED RADIATION STUDIES

The Latouche Point data set was processed at the same time as the Zaikof Bay data set with regard to reflected radiation studies.

4.2.1.1 STUDY 1: NINE CHANNELS OF REFLECTED RADIATION/NO GROUND TRUTH/7094 COMPUTER

The training set selection procedure used by ERIM analysts for this study was the same as that employed in the Phase I Zaikof Bay data processing; for a description of it refer to Section 4.1.1.1, Study 1. The only difference between this study and the Zaikof Bay study is that no annotated photos were available for Latouche Point.

The results of the classification made using the 7094 computer are shown in the map presented in Figure 14. This map was sent to Dr. Zimmerman along with the Phase I Zaikof Bay Map in September, 1976.

4.2.1.2 STUDY 2: FOUR CHANNELS OF REFLECTED RADIATION/INTERACTIVE MODE/MIDAS COMPUTER

The interactive processing of the Latouche Point data set was similar to that described for the Zaikof Bay data set in Section 4.1.1.1 Study 2, only in this case, Mrs. Gnagy did the training set selection.

The results of the MIDAS classification are shown in Figure 15. A legend was developed for this map at the time it was prepared. Unfortunately Dr. Zimmerman took it with him when he left at the end of his visit and no copy of it exists at ERIM.

4.2.2 THERMAL RADIATION STUDY

The thermal level-slice map produced for Latouche Island is shown in Figure 16. Two things it immediately aids the viewer in doing are (1) locating the boundary between deep water/submergent algae and (2) separating the dry sand, rocks, and gravel from vegetation. No unsupervised processing of the Latouche Point data set was attempted.

FIGURE 14. LEGEND

Algae:

1 light red
2 olive brown
3 dark green
4 light green
5 dark orange
6 violet
7 dark red
8 light blue
9 black

water: blue
trees: light orange
grass: yellow
rock: grey
unclassified: white

Scene: 1,600,1,1,531,1

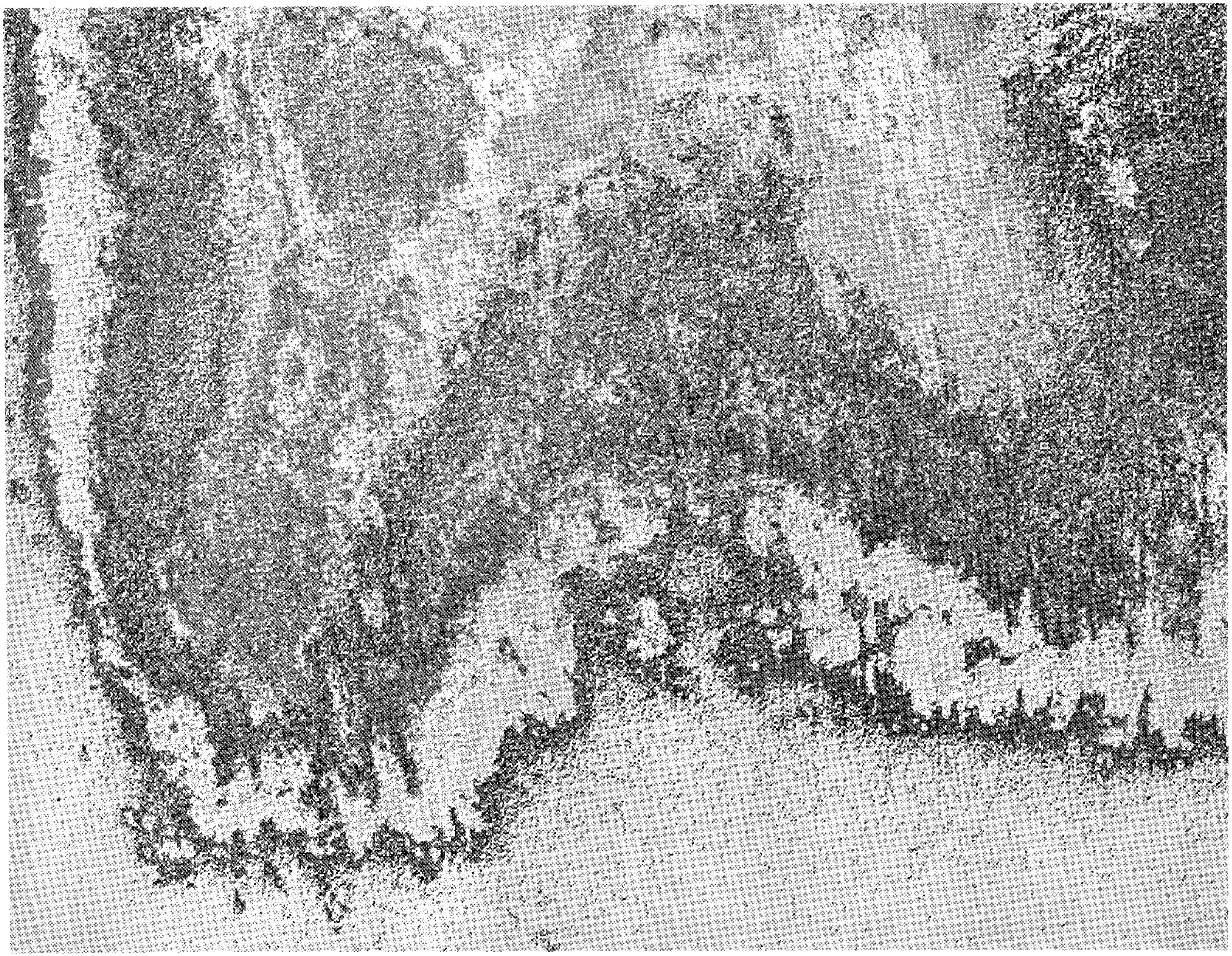


FIGURE 14. SUPERVISED RECOGNITION MAP OF LATOUCHE ISLAND: 9 CHANNELS OF REFLECTED RADIATION/NO GROUND TRUTH/7094 COMPUTER

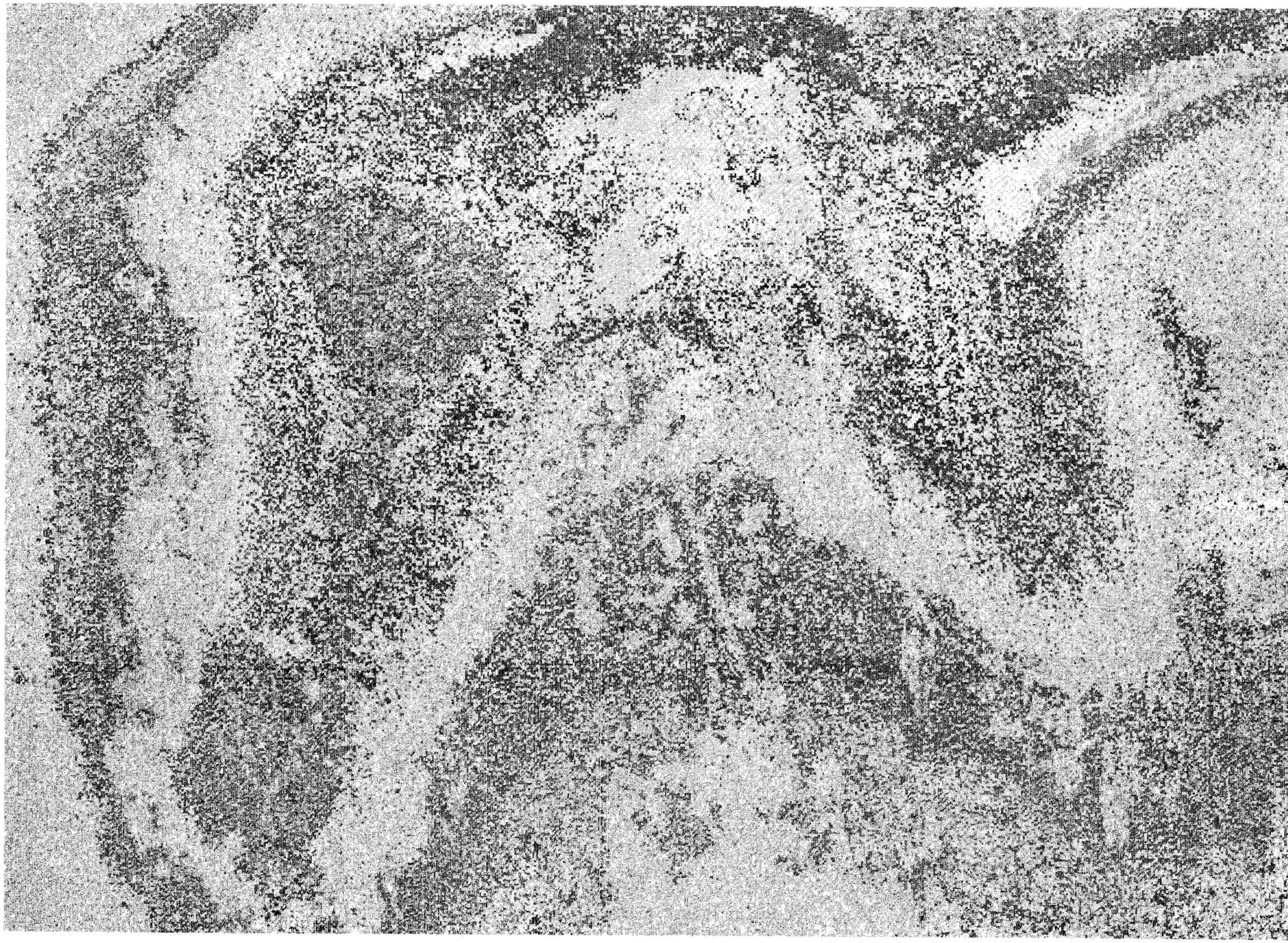


FIGURE 15. SUPERVISED RECOGNITION MAP OF LATOUCHE ISLAND: 4 CHANNELS OF REFLECTED RADIATION/INTERACTIVE MODE/MIDAS COMPUTER

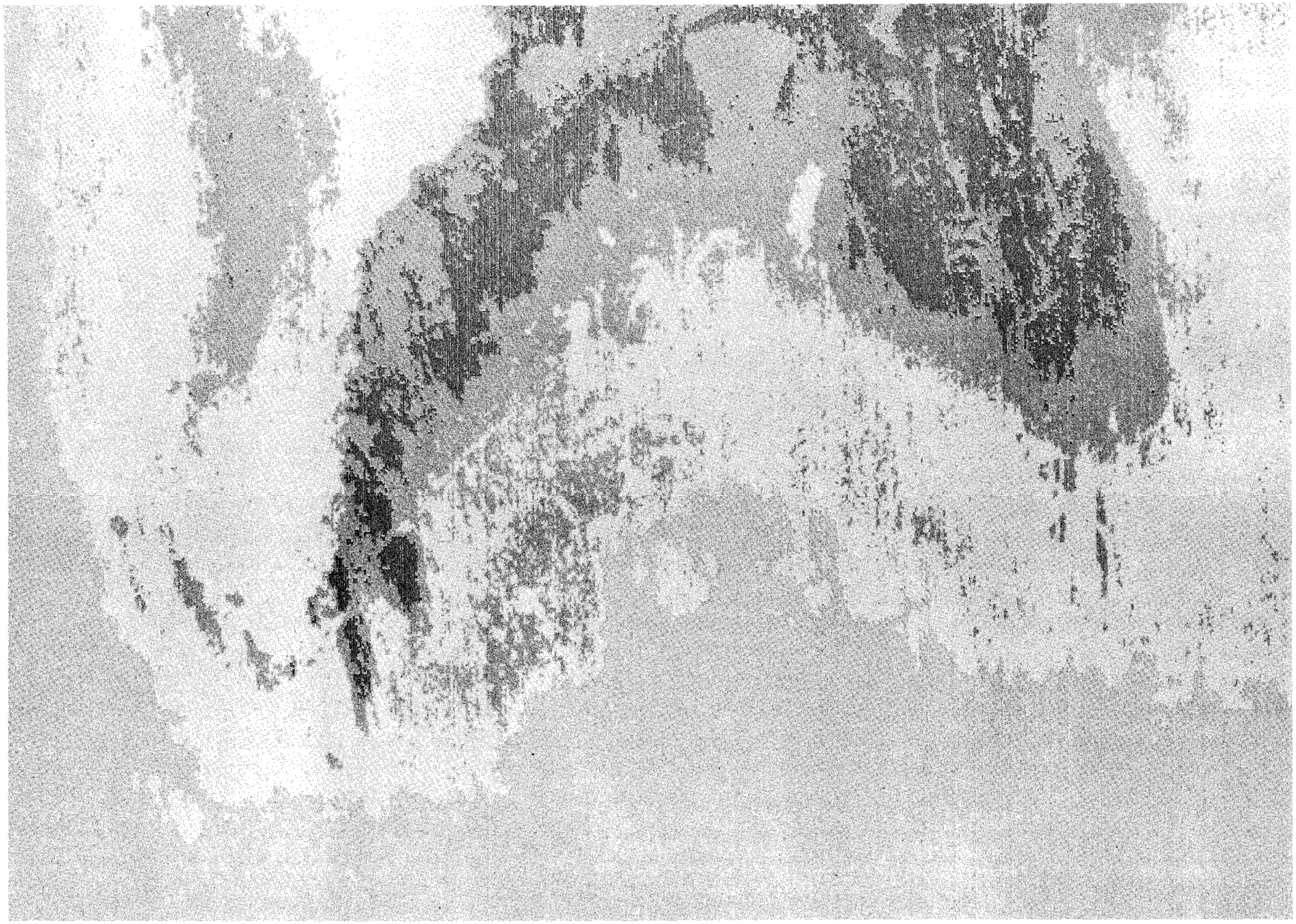


FIGURE 16. THERMAL CONTOURING OF LATOUCHE POINT

Blue: very cool, Yellow: cool, Green: warm, Red: very warm

4.3 CAPE YAKATAGA

The processing for the Cape Yakataga study site was done using the MSS data collected during Run 21. Run 21 was flown at 1,000 ft AGL parallel to the shoreline. A photo of the central portion of the study site is shown in Figure 17.

4.3.1 REFLECTED RADIATION STUDIES

The Cape Yakataga data set was processed as part of the Phase I effort, and it was intended to further process it on both the MIDAS and 7094 computer during Phase II. These plans were not fully realized, however, as explained below in Section 4.3.1.2 under Study 2.

4.3.1.1 STUDY 1: NINE CHANNELS OF REFLECTED RADIATION/NO GROUND TRUTH/7094 COMPUTER

A map was made for Cape Yakataga by the same method used to make the study 1 maps of Zaikof Bay and Latouche Point (Section 4.2.1.1). It is shown in Figure 18.

4.3.1.2 STUDY 2: FOUR CHANNELS OF REFLECTED RADIATION/INTERACTIVE MODE/MIDAS COMPUTER

An interesting situation developed when we attempted to interactively process this data set. The distribution of the algal communities at Cape Yakataga is uneven and often occurs in very narrow linear patches running along rock outcrops and beach ridges. Thus, locating training sets was very difficult. Furthermore, it was hard to produce graymaps on the MIDAS video console which exhibited contrasts similar to those seen in the air photos. It was finally concluded that manual training set selection could not be done well enough for this data set to justify spending the time and money required to complete recognition processing, and further supervised analysis was dropped.

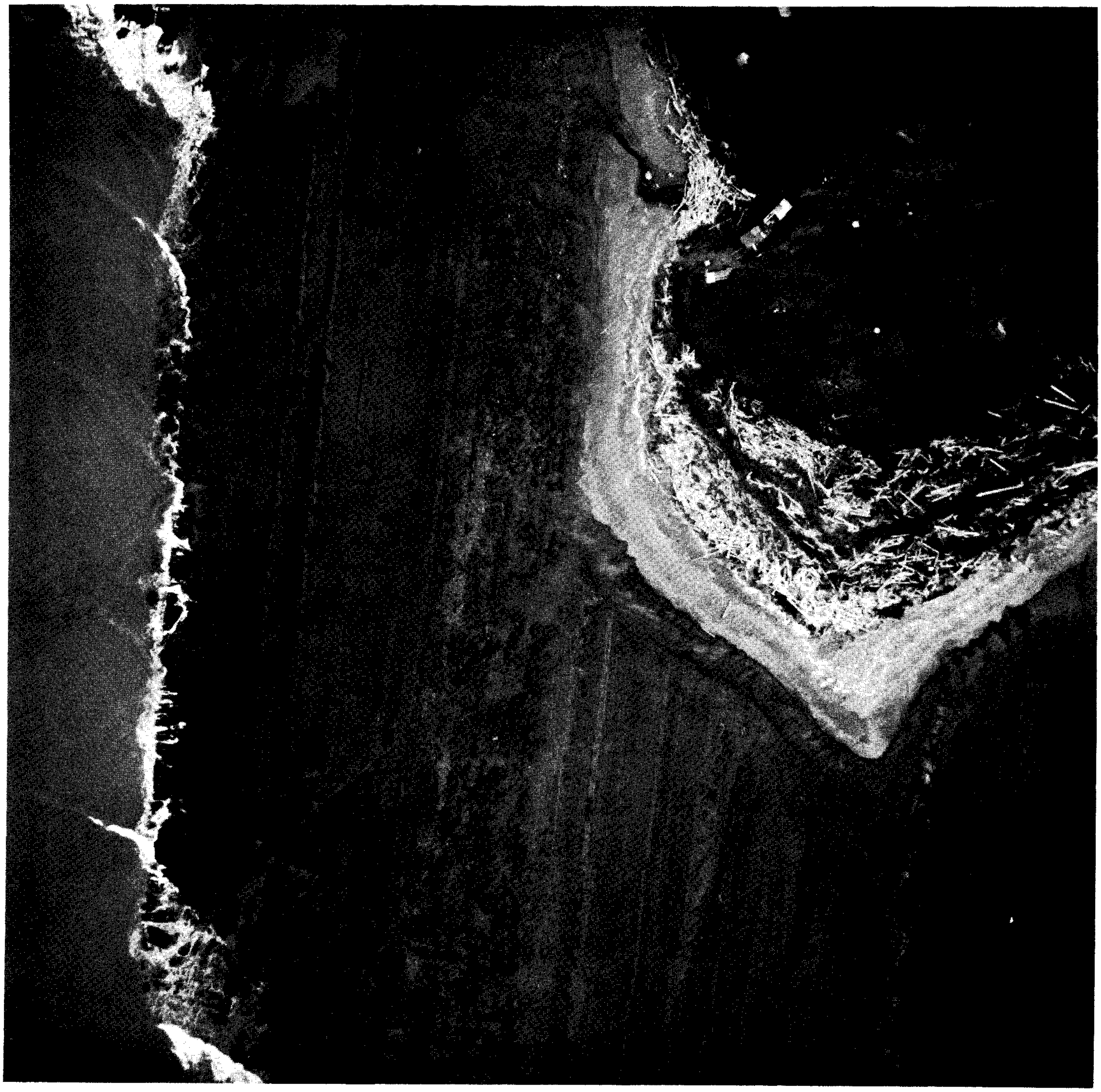


FIGURE 17. VERTICAL AIR PHOTO OF CENTRAL PORTION OF CAPE YAKATAGA STUDY SITE.

FIGURE 18. LEGEND

Algae		Rock	
1:	light red	1:	light blue
2:	olive brown	2:	light orange
3:	dark green		
4:	light green	water:	blue
5:	dark orange	grass:	yellow
6:	violet	unclassified:	white
7:	dark red		
8:	grey		
9:	black		

Scene: 400,1000,1,185,615,1

FIGURE 18. SUPERVISED RECOGNITION MAP OF CAPE YAKATAGA: NINE CHANNELS OF REFLECTED RADIATION/NO GROUND TRUTH/7094 COMPUTER.

4.3.2 UNSUPERVISED RECOGNITION PROCESSING: REFLECTED AND THERMAL RADIATION STUDY

The processing described in this section was chronologically the last to be done. It was inspired partly by the apparent improvement in the scene class separation that could be achieved by including the thermal band. For completeness we initially considered using all the reflected bands, even those that had not been used since Phase I. Thus, we began this study with 10 channels of data.

The same general approach to training set selection via clustering used for Zaikof Bay (Section 4.1.2) was used here; the only difference being that this time the clusters were based on eight channels of data and not four. We had to reduce the initial 10 channels in this study to eight because that is what the clustering algorithm was set up to handle. Based on their poor signal-to-noise ratios (Table 2) channels two and ten were eliminated before clustering. In operation, the algorithm produced 26 clusters. To find out which channels were most useful in describing the clusters, and hence best as a basis for data classification, we ran ALCHAN on the cluster signatures. The results showed that it took only four channels to essentially do as well as could be done. The four channels selected are listed in Table 5.

TABLE 5

FOUR CHANNEL SUBSET SELECTED FOR UNSUPERVISED PROCESSING

Channel	Spectral Band
3	0.475-0.555 blue-green
5	0.540-0.640 yellow
9	0.725-0.905 NIR-2
11	8.0-13.0 Thermal

Significantly, two of the channels (five and nine) are those that were selected for the four channel supervised processing subset. Channel three is a newcomer and so is the thermal band, but the latter was expected to be useful. An EPLOT for the clusters is shown in Figure 19.

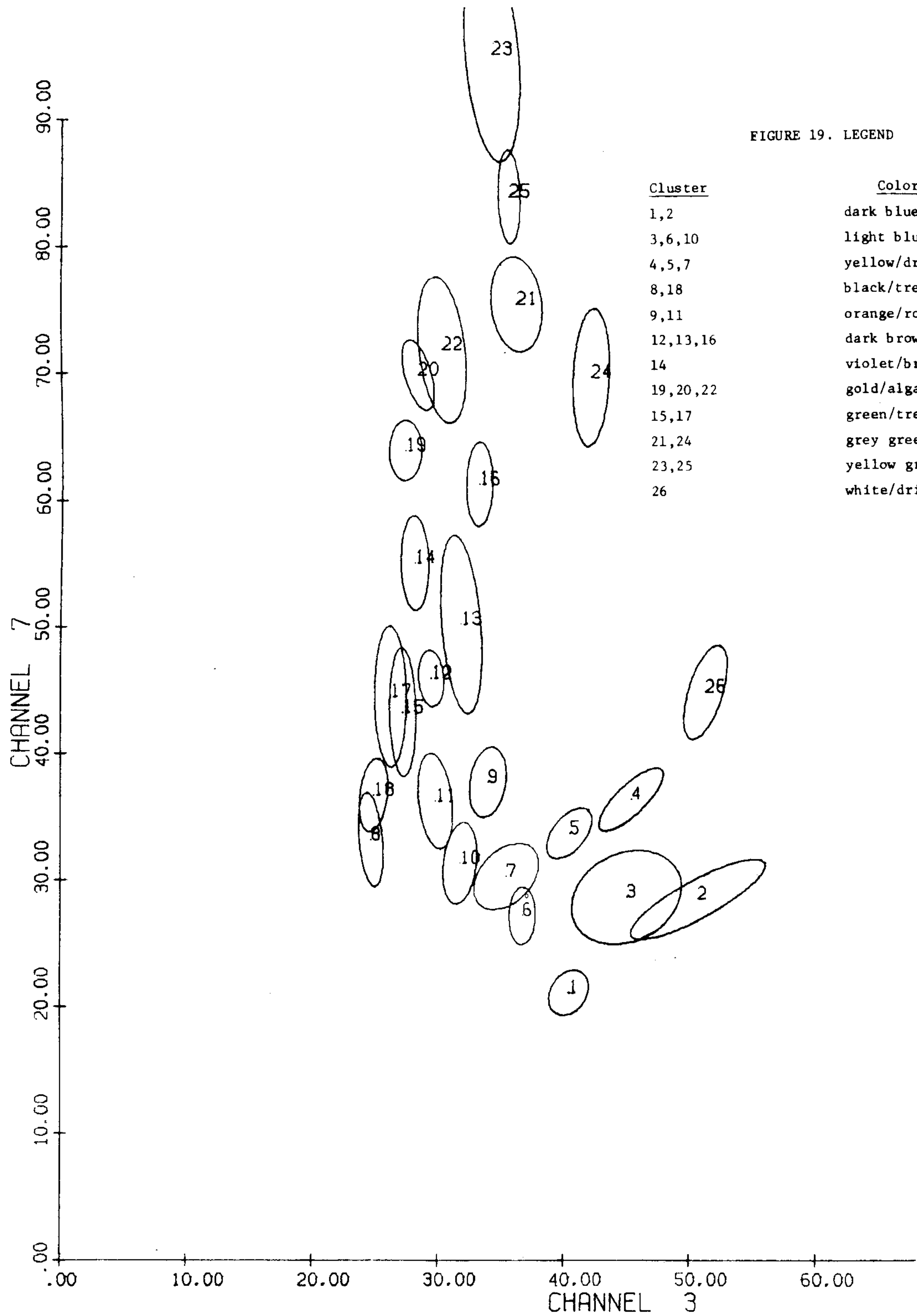


FIGURE 19. LEGEND

Cluster	Color Code
1,2	dark blue/water
3,6,10	light blue/shallow water/wet sand
4,5,7	yellow/dry sand
8,18	black/tree shadows
9,11	orange/rock-fucus
12,13,16	dark brown/algae (Rhodymenia)
14	violet/brush/algae (Rhodymenia)
19,20,22	gold/algae (alaria)
15,17	green/trees/algae (Rhodymenia)
21,24	grey green/driftwood/grass
23,25	yellow green/grass
26	white/driftwood

FIGURE 19. EPLOT OF CLUSTERING-DERIVED TRAINING SETS USED IN UNSUPERVISED RECOGNITION PROCESSING OF CAPE YAKATAGA DATA SET

The color codes assigned to the clusters are those used in the recognition map. A map of the entire study site is shown in Figure 20. An enlargement of the central portion is shown in Figure 21.

Just how good this map is will be discussed in the next chapter.

LEGEND

water: dark blue
shallow water/wet sand: light blue
dry sand: yellow
tree shadows: black
rock-fucus: orange
algae (Rhodymenia): dark brown
brush/algae (Rhodymenia): violet
algae (alaria): gold
trees/algae (Rhodymenia): green
driftwood/grass: grey-green
grass: yellow green
driftwood: white

Scene: 1,1500,1,1,790,1

FIGURE 20. UNSUPERVISED RECOGNITION MAP OF CAPE YAKATAGA: REFLECTED AND THERMAL RADIATION

FIGURE 21. LEGEND

water: dark blue
shallow water/wet sand: light blue
dry sand: yellow
tree shadows: black
rock-fucus: orange
algae (Rhodymenia): dark brown
brush/algae (Rhodymenia): violet
algae (alaria): gold
trees/algae (Rhodymenia): green
driftwood/grass: grey-green
grass: yellow green
driftwood: white

Scene: 400,1000,1,185,615,1

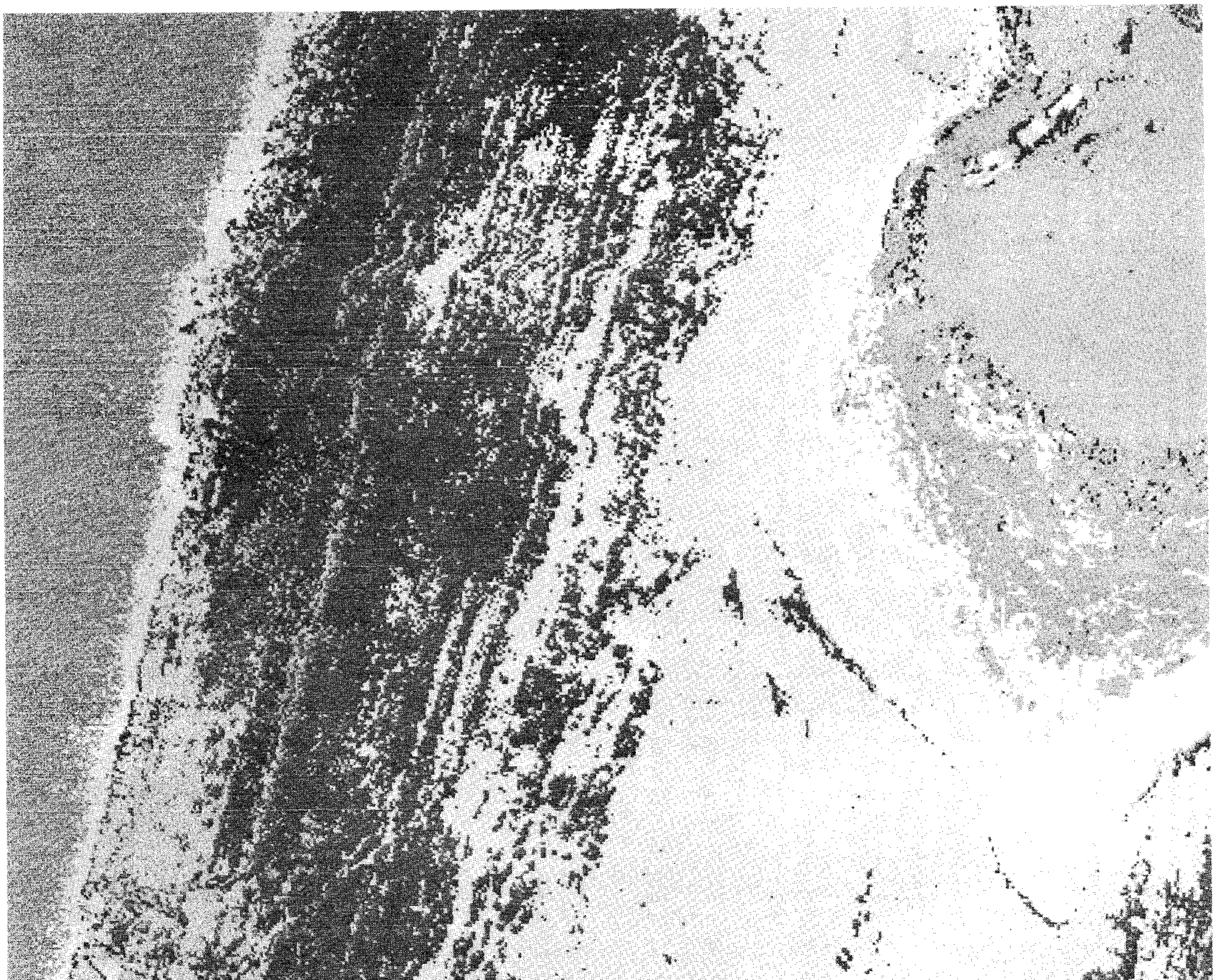


FIGURE 21. ENLARGEMENT OF CENTRAL PORTION OF CAPE YAKATAGA UNSUPERVISED RECOGNITION MAP

5.0
RESULTS AND DISCUSSION

The material in this chapter of the report is organized like that in the Approach (Chapter 2.0), and addresses the specific tasks listed in Figure 2.

5.1 SUPERVISED VS NONSUPERVISED PROCESSING

During the course of this project seven recognition maps were produced: three for Zaikof Bay, and two each for Latouche Point and Cape Yakataga. Of these seven maps, five were produced by supervised processing and two using unsupervised methods. With regard to the supervised maps, three of them were generated on the basis of little to no ground truth, while two of them were produced with the aid of local experts. These products form the basis of the results and analysis in the next few sections. First, we will evaluate the difference ground truth makes in supervised processing. Then we will compare the performance differences between the supervised methods in general and the unsupervised technique. Following that we will examine the tradeoffs in terms of time and cost between the two approaches.

5.1.1 GROUND TRUTH REQUIREMENTS

For this analysis we will be comparing two sets of products, each set consisting of two supervised recognition maps. The first set covers the Zaikof Bay Test Site (Figures 8 and 9) and the other covers Latouche Point (Figures 14 and 15).

Beginning with the Zaikof Bay maps, perhaps the first thing one notices is that water recognition is better for the "no ground truth" map. Water recognition is something we want to discount immediately as being seriously affected by a lack of ground truth. Most likely the better water recognition of Figure 8 is due to the information contained in the additional spectral bands used in its preparation.

We do not, however, think this is true of other differences we have noted. For example, the land/water boundary is better in Figure 9. Quite possibly Dr. Zimmerman's intimate knowledge of the width of the first algal zone helped him place his training set for this type more accurately. Dr. Zimmerman's knowledge presumably also helped him accurately locate the training set for the Mixed Zone, which was not recognized (and presumably not even trained for) in Figure 8.

Figure 9 is not perfect, however, because the Mixed Zone is confused with brush. A further observation we make at this point is that Figure 9 appears more "grainy", i.e., the algal species recognition (with the exception of Alaria) is quite interspersed and does not exhibit as clearly the zonation apparent in Figure 8 or for that matter in Figure 7. Which map is a truer representation of the ground we at ERIM do not know, but our opinion is that reality actually lies somewhere between the two.

One further thing we should like to point out here is that the further away from the shoreline or tree line that Dr. Zimmerman tried to pick training sets, the harder he found it to accurately locate himself in the video graymap. This experience points out the fact that even the best ground truth may be hard to apply to remote sensing data and a big ground truth effort is no guarantee of fool-proof processing. In general, however, we feel that the local experience of the ground truth team did contribute to a better map in the case of the Zaikof Bay study site.

The complexity of the Latouche Point study site makes it very difficult to reach even qualitative conclusions. The only obvious difference between the no ground truth map (Figure 14) and the Interactive Mode map (Figure 15) is that deep water appears better recognized in Figure 14, probably for the same reason it does in Figure 8, the Zaikof Bay set. Many of the major patterns (not necessarily coded in the same colors) in both maps (Figure 14 and Figure 8) appear to represent similar vegetation zones. Thus, we would not be suprised to learn that the accuracies of both maps are similar, so for this study site we may have an example of where having good truth did not necessarily improve recognition performance.

5.1.2 RECOGNITION PERFORMANCE EVALUATION

For comparing the results of supervised and unsupervised recognition processing we again have two sets of maps. These map sets cover Zaikof Bay and Cape Yakataga. For Zaikof Bay there are three maps (Figures 8, 9, and 12) and for Cape Yakataga there are two maps (Figures 18 and 20).

One's initial reaction to Figure 12 of Zaikof Bay is that it appears "cleaner" than the other two maps. There are several reasons for this: the first is that the shoreline is more accurately represented here by the light blue/gold interface than in the other two maps. This can be verified by closely inspecting the vertical airphoto in Figure 7. The submergent zone that appears as pink in Figure 8 is light blue in Figure 12, but is poorly defined in black in Figure 9. On the other hand, the inland rock zone was not well recognized (Figure 12). A band of dark blue appears in the center of the rock zone in Figure 12 (look closely!) indicating some confusion with deep water. This confusion does not occur in Figure 9 and only to a limited degree in Figure 8. The fact that a lot of light blue occurs in Figure 12 does not indicate serious error and is in fact nearly the same situation that exists in Figure 9, where the shallow water zone is similarly mapped in the same color as part of the rock area. The only difference is the color coding, and the association one makes with the colors used.

Grass recognition in Figures 9 and 12 appears similar and better than that in Figure 8. Brush recognition, however, looks similar in Figure 8 and Figure 12, which both look better than Figure 9. Sand recognition also looks about the same in Figures 12 and 8 and in both cases less "grainy" than Figure 9. Individual driftwood logs can be spotted in both Figures 12 and 9, but the clearest representation of the large pile of driftwood in the right side of the scene appears in Figure 12.

With regard to the accuracy of the algal zone mapping, it appears that Figure 12 combines the best features of both Figure 8 and 9. The Alaria Zone (red) of Figure 9 is the light blue of Figure 12. The Fucus Zone of Figure 9 (yellow) is better defined and appears more cohesive, as it probably is on the ground, in Figure 12 (gold); and the same is true of the Ulva (green) and Mixed (orange) zones of Figure 9 which probably correspond with the pink and violet zones respectively of Figure 12. Another major benefit shared by both Figure 8 and Figure 12 is the better definition of beach topography. The many rock ridges, boulders, fissures, etc., that help to orient one's self clearly stand out in Figure 12. Thus, for the Zaikof Bay data set it appears, on a qualitative basis, that clustering, i.e., the unsupervised approach, produced results as good if not better than the supervised methods.

An examination of the unsupervised recognition map of the entire Cape Yakataga study site (Figure 20) and a comparison of the enlarged supervised and unsupervised maps (Figures 18 and 21, respectively) of its central portion lead to essentially the same conclusions. Overall, the clustering technique has again resulted in a "cleaner" map, and a map with more apparent topographic and geomorphic detail. Comparison of the spatial occurrence of the cluster recognition results shown in Figure 21 with air photos annotated by Ms Gnagy on which she roughly outlined the areas where the most common type of algae occur on the study site, has tempted us to tentatively apply the names seen in the legend to the color classes indicated. Shoreline detail also appears more accurate in Figure 21 than Figure 18, compared with the photo in Figure 17.

The one major difference between the two maps is the percentage of the littoral zone that is classified as algae. Figure 18 has much more of its center portion designated as algae. What has apparently occurred, is that in the absence of ground truth, different colors of sand have been mistaken for algae and training sets established to recognize these "zones" as well. Renaming the "algae classes" that occur in this zone as sand and color coding them accordingly would probably produce a map more similar to Figure 21. For example, consider what Figure 8 would look like if the dark red, light orange, dark orange and gray algae classes were coded light blue like the Rock 1 class. The result would be a fairly homogenous central map portion like that of Figure 21.

So, for Cape Yakataga, as with Zaikof Bay, it appears that unsupervised recognition techniques have produced better results. We expect that quantitative evaluation of recognition accuracy will bear this conclusion out, and look forward to hearing the results of such analyses which we expect the sponsor will undertake.

5.1.3 TIME AND COST CONSIDERATIONS

Representative time and cost statistics for what it would take to do a given remote sensing inventory project operationally are among the most difficult figures to obtain in a research environment. This project is no exception. Simply using the expenditures and schedules experienced during the course of the project would hardly be fair. Neither do we want to ignore what we learned and simply extrapolate from commercial operations that bear a faint resemblance to the Alaska survey situation. In order to be totally responsive to the sponsor's needs it is necessary to use elements of both approaches, and this is what we have done.

In the following discussion we have used the schedules, difficulties experienced, and results obtained <u>from the present project</u>, but in a <u>relative</u> sense, to look at the time, staff, and supporting resources required to conduct the type of airborne survey evaluated in this study, while cost data has generally been derived from actual <u>operational survey projects</u> with similar instrumentation and flight plan specifications and data processing methods.

A logical place to begin cost analysis is with data collection. To provide a basis on which to determine costs a hypothetical survey project was postulated. In this hypothetical project we planned to accomplish all the necessary flying, including transit time, within one month. Transit time of the aircraft to and from Alaska and to get on station for each data collection run is estimated to require 60 flight hours. Forty hours of data collection was budgeted in, which, since 30 flight miles of data can be collected in one hour, means that 1200 miles of data can be collected. If we assume 10 days for travel to and from Alaska, the aircraft will be on station for 21 days. If we further assume that weather conditions are suitable, for data collection one of three days (cloudfree tables; ASP, 1968), then seven days are available for flying in which to use the 40 data collection hours. This works out to an average mission length of six hours, during which both scanner data and color photography (70 mm) are collected.

In developing the cost figures for data collection we have done it two ways. In Mode I we have figured expenses on the basis of commercial rates we encountered during the data collection phase of this project. In Mode 2 we have figured costs on what we think it would cost if ERIM collected the data using its own aircraft and scanner. These figures are broken down in Table 6 and followed by an explanation of how they were derived.

TABLE 6

Mode 1: Lease a commercial scanner and install it in a rental plane

Mode 2: ERIM's M-8 scanner in an ERIM aircraft

Category	Mode 1 Cost	Mode 2 Cost
Labor	7,000	34,000
Travel	7,000	14,000
Materials	4,000	4,000
Aircraft	25,000	14,000 (POL)
Scanner	53,000	0
TOTALS	96,000	66,000

Breakdown of Expenses

Labor:

Mode 1: salary and overhead of technician for one month

Mode 2: salary and overhead for a five-man crew for one month; one crew chief, two pilots, one technician, one scanner operator

Travel:

Mode 1: airline ticket and per diem of technician and pilot: \$80 day x 30 days x two persons = \$6,000 x two x \$500/ticket = \$7,000

Mode 2: per diem of five-man crew for one month and two commercial airline tickets

Materials:

Mode 1: HDDT's, film, liquid nitrogen, camera rental, miscellaneous

Mode 2: same as above except for camera rental

Aircraft:

Mode 1: Rental of commercial aircraft (e.g., twin-engine Cessna 301) @ $250/hr x 100 hrs for 30 days = $25,000

Mode 2: The only cost associated with the use of an ERIM aircraft is for gas, oil, lubrication and maintenance. The figure quoted is for 100 hours of operation.

Scanner:

Mode 1: This figure reflects the rental cost $1,000/day and installation cost $5,000 of a commercial scanner such as a Bendix M^2S unit.

Mode 2: There is no charge for use of the ERIM-8 scanner beyond personnel and aircraft expenses covered earlier.

Based on the above data a data collection cost per flight line mile can be calculated for each mode of operation. These figures are:

Mode 1: $80/flight line mile

Mode 2: $55/flight line mile

On the basis of costs alone, it appears that Mode 2, having ERIM collect data, is preferable. Another point worth mentioning at this time is that ERIM scanner data has traditionally been the finest multispectral data routinely collected. Furthermore, the spectral bands in the ERIM scanner are located differently from those in other multispectral systems, based on many years of research in terrain analysis, and we feel they represent the optimum set-up for vegetation mapping.

If it was decided to go the Mode 1 commercial route, this is one place a government agency potentially could save money by using a government-owned aircraft and flight crew.

Data collection is only one side of the coin, however, before any decisions can be made the data has to be processed, maps made, and information extracted from them. These steps comprise the data processing effort of our hypothetical survey project. For the sponsor to be able to evaluate the consequences of their alternatives in terms of cost as well as performance we felt it was necessary to provide scenarios representing the main approaches to handling the data processing. On the basis of the results of this project and our experience, we identified three possible scenarios for handling the volume of data collected in this hypothetical project. These are:

Scenario 1: Supervised digital recognition processing

Scenario 2: Unsupervised digital recognition processing

Scenario 3: Unsupervised digital recognition processing on MIDAS

Each of these three scenarios will be discussed in turn and then a cost comparison and summary made.

Before we turn to discussion of the individual scenarios, however, let us make a few more assumptions about the nature of the hypothetical survey project. First, processing all the data digitally is unreasonable. We are talking about 1200 data miles, with 2100 scan lines per mile and 800 points across each line. This amounts to more than 1.68 million pixels per mile or a total of over two billion pixels of data x the number of channels collected. This is the equivalent of 266 Landsat frames. To avoid the expense of digitally processing all of this data we recommend the following approach in which all the data is utilized but processing costs are greatly reduced.

In most environmental surveys it turns out that only a fraction of all the data collected is ever used in decision making. Sampling is one reason for this, data collection problems are another, often only a few sites are actually found to be of interest, and so on. We feel this could well be the case with our hypothetical project. We have thus assumed that we really only need to digitally process only 1/6 of the total data set or 200 data miles. The next question that logically arises is which 200 miles? We feel that candidate sites for digital processing can be effectively selected on the basis of visual analysis of analog playback of all the data.

Analog playback is an electronic process whereby a channel of scanner data is electronically modulated in the form of a CRT pulse and recorded on film as a 70 mm filmstrip (see Figure 22). The result is a strip of imagery resembling aerial photography.

Then, biologists, using this imagery, vertical photography, maps and local knowledge of the area, can zero in on those sketches of shoreline which they feel appear to contain sensitive algae communities about which they want more information.

The description of the three scenarios for digitally processing 200 flightline miles is as follows.

SCENARIO 1: Supervised Digital Recognition Processing

This type of processing is the most conventional form of remote sensing data processing. The general steps in the sequence are diagrammed in Figure 23.

A brief description of the supporting processing for each step, plus the cost and time required to finish it, are furnished in the following breakdown and keyed to Figure 23. Computer costs are based on the rates associated with the University of Michigan's Amdahl 470/V6, a large modern general purpose time-sharing digital computer. The costs presented for each step, however, reflect the entire cost for each step, including salary and wages, overhead and computer costs. ERIM's corporate cost structure was used as a general guideline for figuring personnel expenses.

Step 1: The purpose of this step is to produce a 70 mm filmstrip image of one channel of data

Cost $2,500 Time Required: 2 weeks

Step 2: The purpose of this step is to select a subset of 200 miles of data from the original 1200 miles. This would probably require two to three persons at the GS-12 level from the sponsoring agency to be involved.

Cost: borne by the agency Time required: 3 weeks

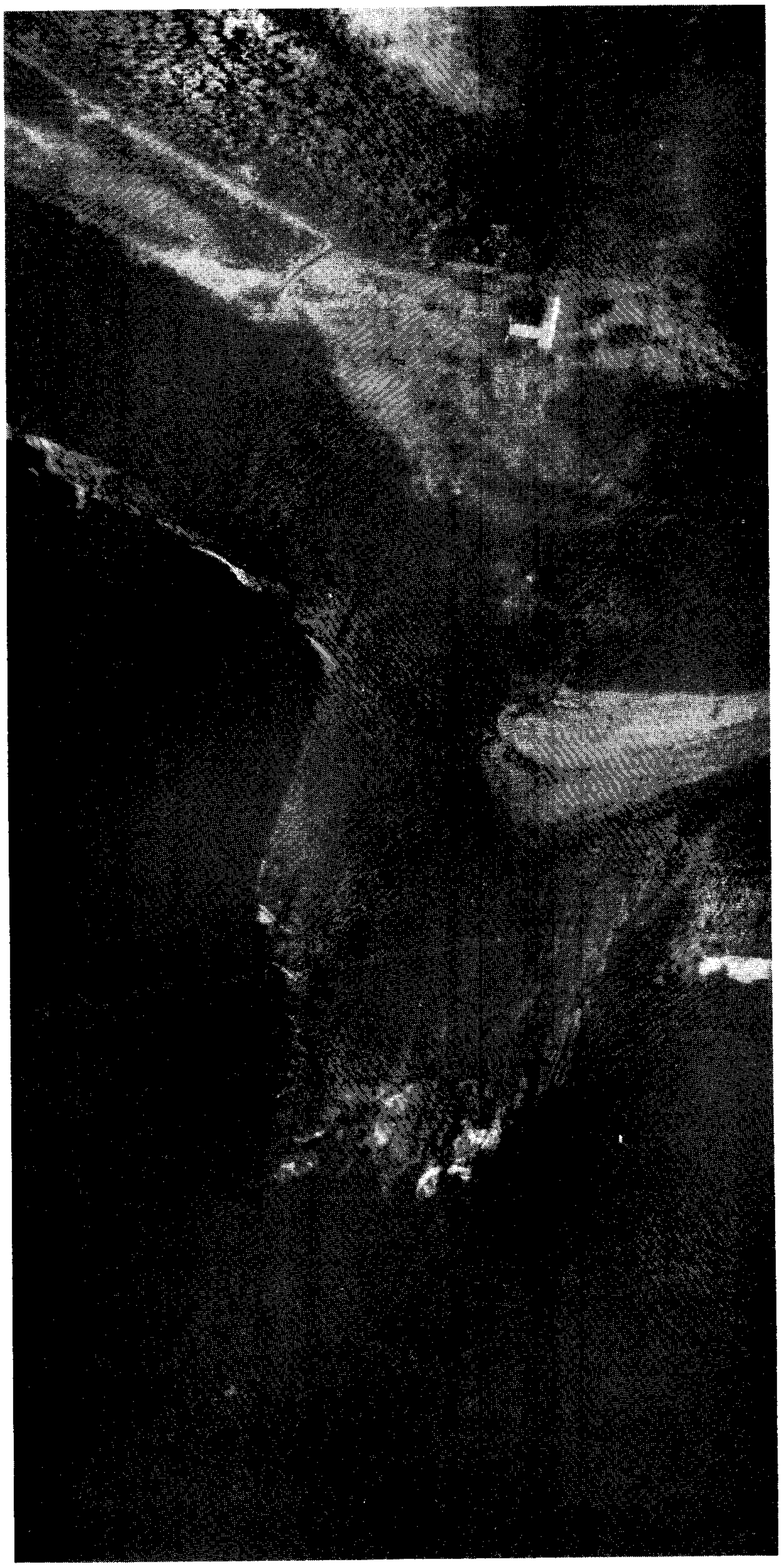
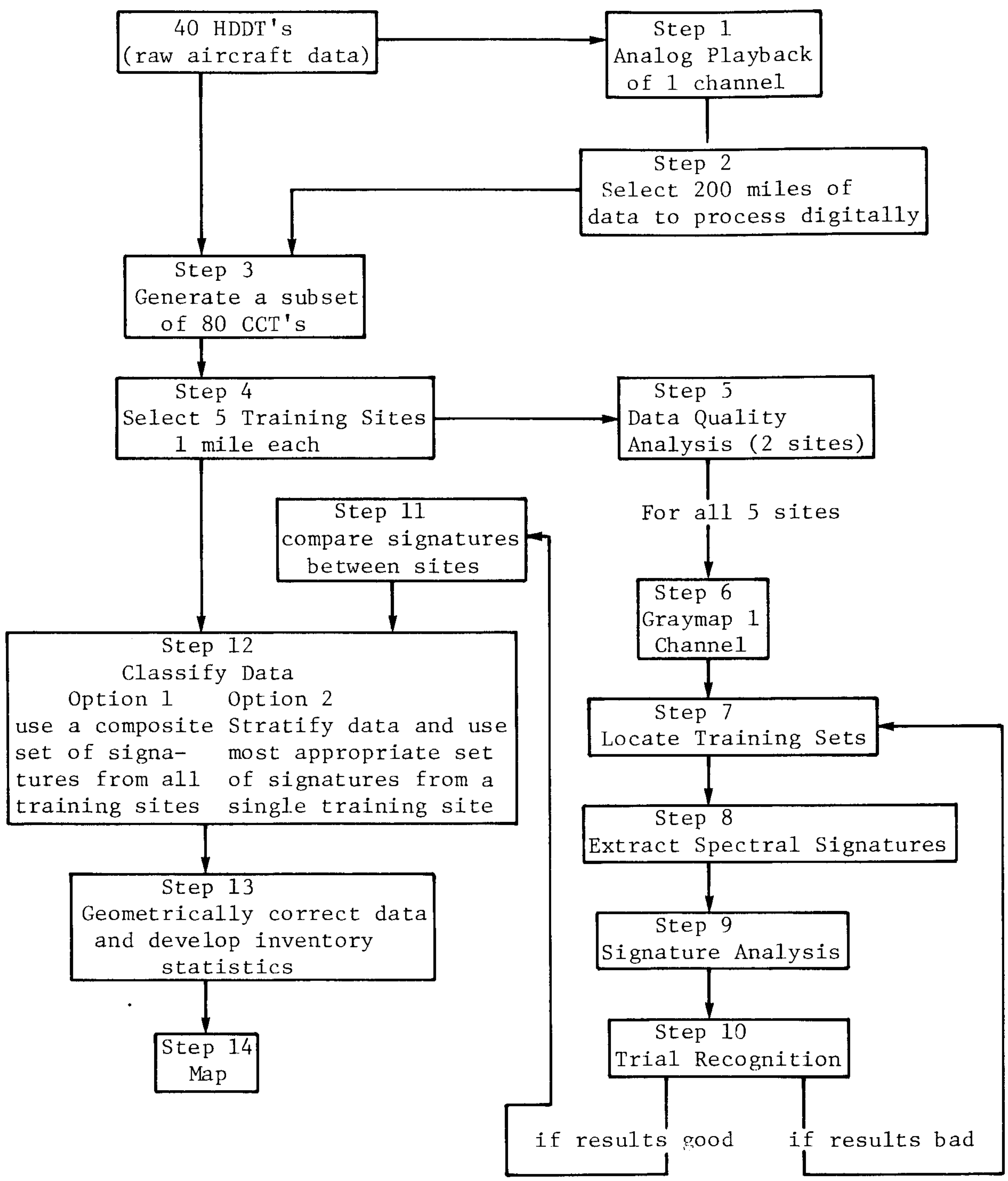


FIGURE 22. 70mm FILMSTRIP ANALOG PLAYBACK OF RUN 21, CAPE YAKATAGA, CHANNEL 9.

FIGURE 23: Scenario 1: Supervised Digital Recognition Processing



Step 3: The purpose of this step is to generate a set of tapes that can be read by the general purpose computer
Cost: $12,000 Time Required: 2 weeks

Step 4: In this step five study sites are selected which contain representative samples of the biological communities it is desired to inventory. It could be done concurrently with step 2 by the same persons.

Step 5: This step would be done for only two of the five study sites, selection could be based on the best and worst environmental conditions and/or sensor performance.
Cost: $1,250 Time Required: 1 week

Steps 6, 7, 8: These steps represent training the computer and would be done for all five sites.
Cost: $2,500 Time Required: 2 weeks

Step 9, 10: This step would involve classifying a portion of each study site and evaluating the results.
Cost: $4,500 Time Required: 3 weeks
Note: for each repeat of steps 6-10 an additional $500/study site is required.

Step 11: The purpose of this analysis is to see how similar the signatures of the different sites are; things to look at are unique signatures; signatures that can be combined; whether the signatures can be transformed for better recognition performance using signature extension techniques; etc.
Cost: $1,250 Time Required: 1 week

Step 12: Classification would be done in small batches over a two week period using a maximum likelihood decision rule: about four miles a day could fit in.
Cost: $18,000 Time Required: 4 weeks

Step 13: The purpose of this step is to remove scan angle effects and standardize the ground as represented by each pixel.
Cost: \$5,500 Time Required: 2 weeks

Step 14: The maps would be made on the Ink-Jet printer. It would be dedicated to the project 1/2 time.
Cost: \$6,500 Time Required: 2 weeks

Materials: 80 CCT's, 13 DIVA Disks, other supplies
Cost: \$3,500

Additional Time required for travel, communications, etc.: 2 weeks

Grand Totals: Cost: \$57,000 Time Required: 6 months

On a per mile basis the data processing cost for Scenario 1 is \$285.00

SCENARIO 2: UNSUPERVISED DIGITAL RECOGNITION PROCESSING

This scenario is essentially similar to scenario one except for the manner in which training sets are selected. Instead of manually identifying areas of representative materials and extracting signatures from these locations, clustering is used to locate samples of spectrally similar materials. All other assumptions are the same. Where the description of the purpose or work involved in a step is similar to Scenario 1 it is indicated. See Figure 24.

Step 1: See Scenario 1, Step 1
Cost: \$2,500 Time Required: 2 weeks

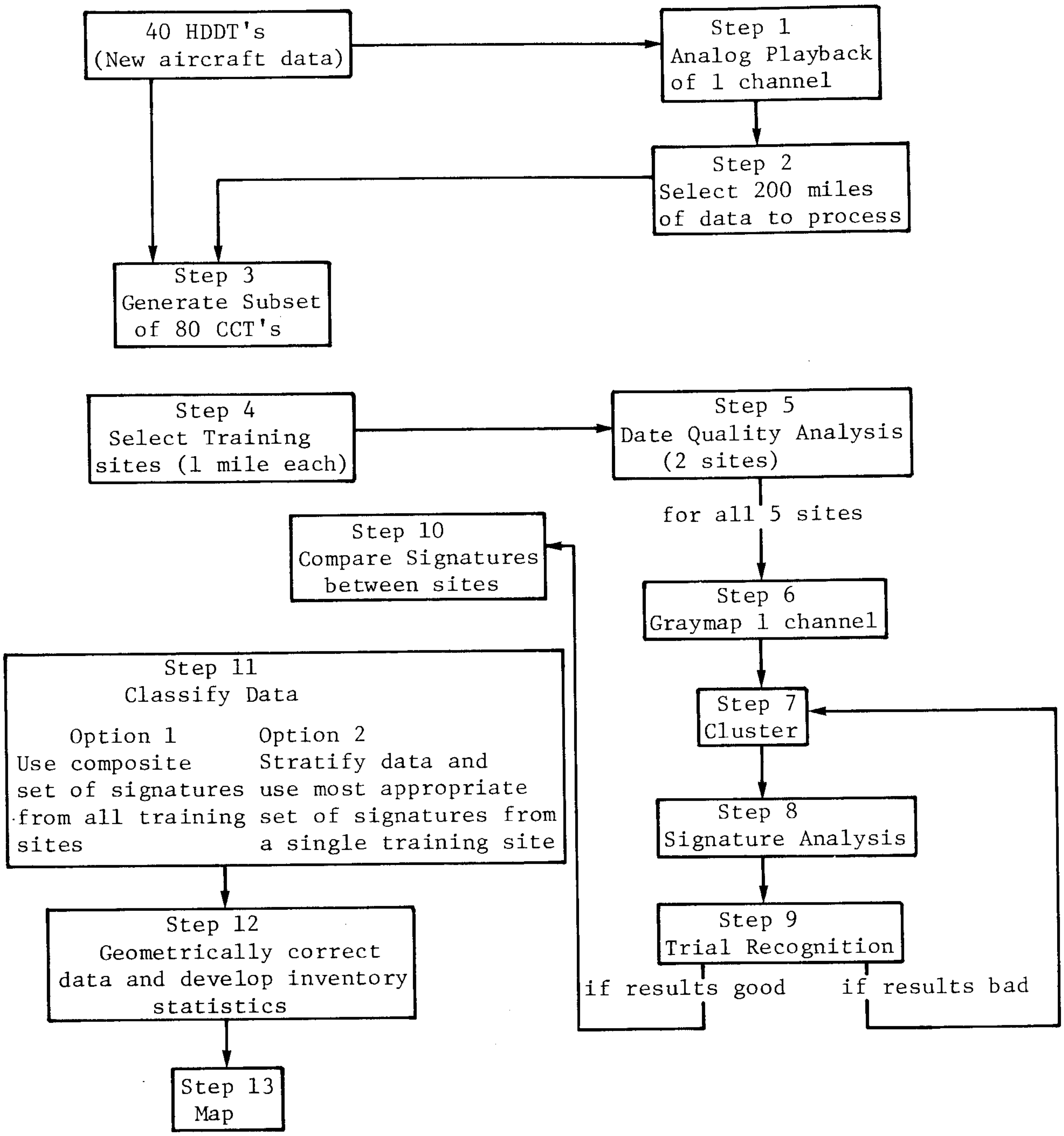
Step 2: See Scenario 1, Step 2
Cost: borne by the sponsoring agency
Time Required: 3 weeks

Step 3: See Scenario 1, Step 3
Cost: \$12,000 Time Required: 2 weeks

Step 4: See Scenario 1, Step 4

Step 5: See Scenario 1, Step 5

FIGURE 24: Scenario 2: Unsupervised Digital Recognition Processing



Step 6, 7: The purpose of these steps is to generate training set statistics based on the inherent spectral properties of the data.

Cost: $3,000 Time Required: 2 weeks

Steps 8, 9: See Scenario 1, Steps 9, 10

Cost: $4,500 Time Required: 3 weeks

Step 10: See Scenario 1, Step 11

Cost: $1,250 Time Required: 1 week

Step 11: See Scenario 1, Step 12

Cost: $18,000 Time Required: 4 weeks

Step 12: See Scenario 1, Step 13

Cost: $5,500 Time Required: 2 weeks

Step 13: See Scenario 1, Step 14

Cost: $6,500 Time Required: 2 weeks

Materials: $3,000

Additional Time Requirements: 2 weeks

GRAND TOTALS: Cost: $57,500 Time Required: 6 months

On a per mile basis, the data processing cost for Scenario 2 is $287.50.

SCENARIO 3: UNSUPERVISED DIGITAL RECOGNITION PROCESSING ON MIDAS

The latter part of Scenario 3 (Step 8-14) is radically different from Scenarios 1 and 2 because instead of being accomplished on a time-shared, general purpose, digital computer, they are performed on a dedicated, high-speed, special purpose computer developed specifically to handle large volumes of remote sensing data. The individual steps with their associated cost and time required are described below: (See Figure 25).

Step 1: See Scenario 1, Step 1

Cost: $2,500 Time Required: 2 weeks

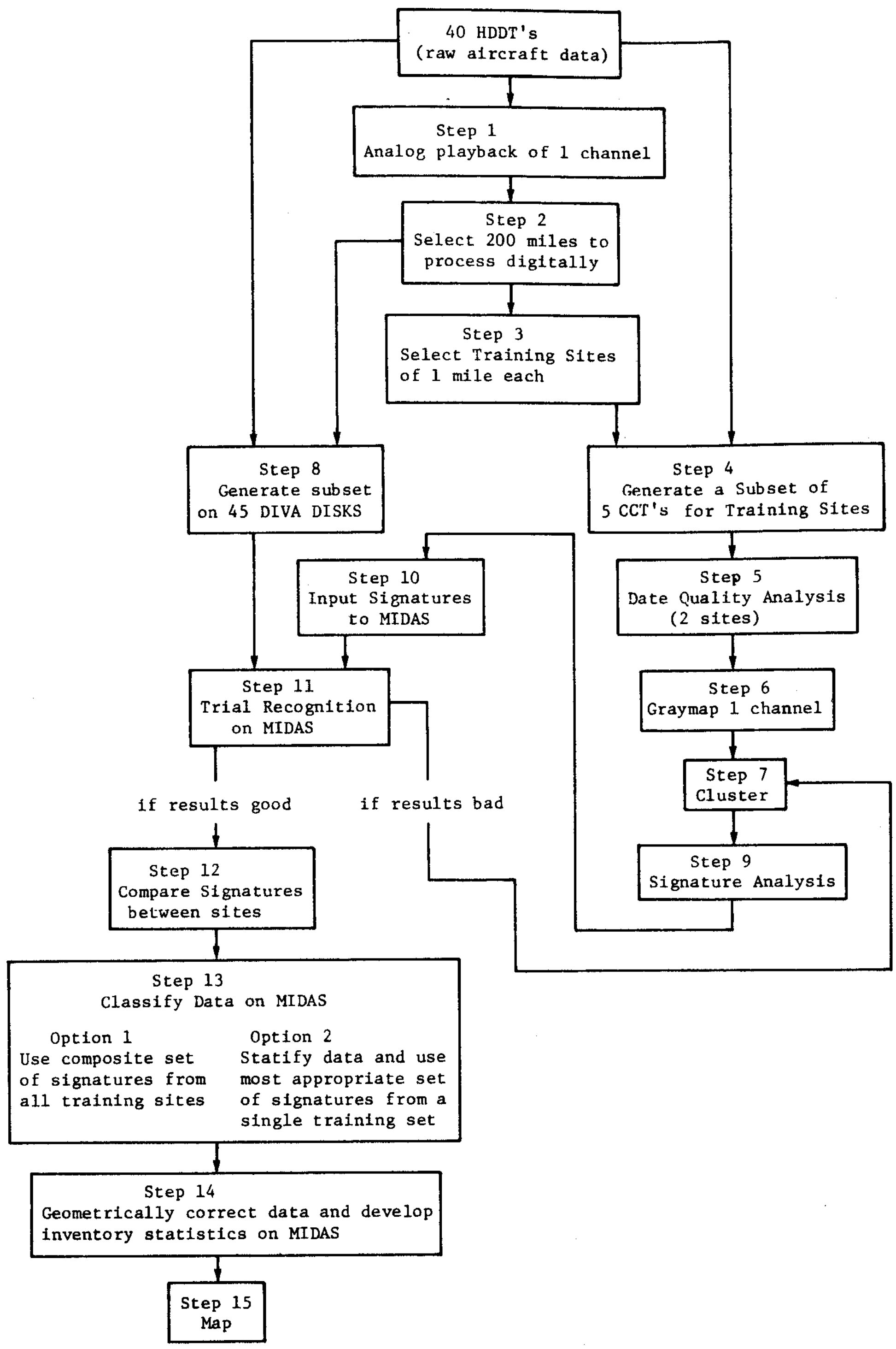


FIGURE 25: Scenario 3: Unsupervised Digital Processing on MIDAS

Step 2: See Scenario 1, Step 2

Cost: borne by sponsoring agency

Time Required: 2 weeks

Step 3: See Scenario 1, Step 4

Step 4: See Scenario 1, Step 3

Cost: $750 Time Required: 1 week

Step 5: See Scenario 1, Step 5

Cost: $1,250 Time Required: 1 week

Step 6,7: See Scenario 2, Steps 6, 7

Cost: $3,000 Time Required: 2 weeks

Step 8: 200 miles of the total 1,200 mile data set are loaded onto DIVA Disks via MIDAS for rapid access

Cost: $8,700 Time Required: 2 weeks

Steps 9, 10, 11: The purpose of this step is to determine if accurate enough recognition is being achieved by classifying a small portion of each of these study sites and evaluating recognition performance. $3,000 of the cost and 2 weeks of the time shown for software development to enable signature input to MIDAS via punched cards.

Cost: $6,000 Time Required: 4 weeks

Step 12: See Scenario 1, Step 11

Cost: $1,250 Time Required: 1 week

Step 13: On the MIDAS Computer one disk of data (11.25 flight miles) can be classified in 30 minutes.

Cost: $3,700 Time Required: 1 week

Step 14: The purpose of this step is to remove scan angle effects and standardize the ground area represented by each pixel before generating the inventory statistics. $3,000 and two weeks of software development support are figured into the logistics of this step.

Cost: $5,000 Time Required: 3 weeks

Step 15: The maps will be made on the ink-jet printer attached to MIDAS. MIDAS will be dedicated 1/2 time. The cost is substantially low for this step in this scenario because the data is already loaded on the DIVA Disks.

Cost: $4,500 Time Required: 1 week

Materials: 57 DIVA Disks, 5 + CCT's, other supplies Cost: $8,000

Additional Time Required: 2 weeks

Grand Totals: Cost: $44,650 Time Required: 5.5 months

On a per mile basis, the data processing cost associated with Scenario 3 is $222.80.

SUMMARY

In this section of the report we have covered a lot of material and this summary of it should be helpful in putting it all in perspective.

Figure 26 graphically presents the costs associated with performing the hypothetical inventory task we proposed. On the basis of these figures it is clear that data processing is the most expensive aspect of multispectral remote sensing. It is also clear that various data collection and processing alternatives can result in substantial savings in cost. Interestingly enough, in the case of this hypothetical project, it turns out that the recommended approach (ERIM data collection and clustering) can be done for the least expense.

FIGURE 26. SUMMARY OF COST DATA FOR HYPOTHETICAL MULTISPECTRAL SURVEY OF ALASKAN COASTLINE.

Data Collection	Data Processing	Project Cost/ Digitally Processed Flightline Mile	Total Project* Cost	Rank
MODE 1-$80/FL Mile	Scenario 1-$285.00/mi	- $365.00	$153,000	5
	Scenario 2- 287.50/mi	- $367.50	$153,500	6
	Scenario 3- 222.80/mi	- $302.80	$140,560	4
MODE 2-$55/FL Mile	Scenario 1-$285.00/mi	- $340.00	$123,000	2
	Scenario 2-$287.50/mi	- $342.50	$123,500	3
	Scenario 3-$222.80/mi	- $277.80	$110,650	1

*The total project is considered to be a survey of 1200 miles of Alaskan coastline with 1200 miles of the data mapped in analog form and 200 miles inventoried with digital processing techniques.

5.2 OPTIMUM SENSOR SYSTEM PARAMETERS

In order of presentation we discuss the following topics in this section of the report: 1) The spectral bands most useful in this study, 2) performance differences between reflected bands and thermal band, and 3) the effect of data quality on the results of this analysis.

The question of what are the optimum spectral bands for a multispectral scanner is a complicated one. Any selection represents a compromise involving many factors, such as detector sensitivity, sun illumination, atmospheric transmittance, and reflectance characteristics of the target, etc. In the past ERIM has performed many studies aimed at finding the ideal compromise as part of the research and design work supporting its own sensor development programs. For general vegetation analysis the following spectral band requirements were identified (Lowe, et al., 1973):

TABLE 7

OPTIMUM SPECTRAL BANDS FOR VEGETATION ANALYSIS

Band	$\lambda_1 - \lambda_2$ (μm)	Sensitivity
1	.42-.47	
2	.62-.68	
3	.69-.75	1% reflectance
4	1.0 -1.4	
5	1.5 -1.8	
6	2.0 -2.6	
7	8.3 -9.3	1°K
8	10.5 -12.5	

The findings of this work shows up in the design of ERIM's latest scanners system, the M-7 and M-8 (see Figure 27). Many of the bands of the M-7 and M-8 scanners coincide exactly with the theoretical optimum, others do not. The reason some bands are shifted is because of their importance for other applications, such as geologic or marine resource

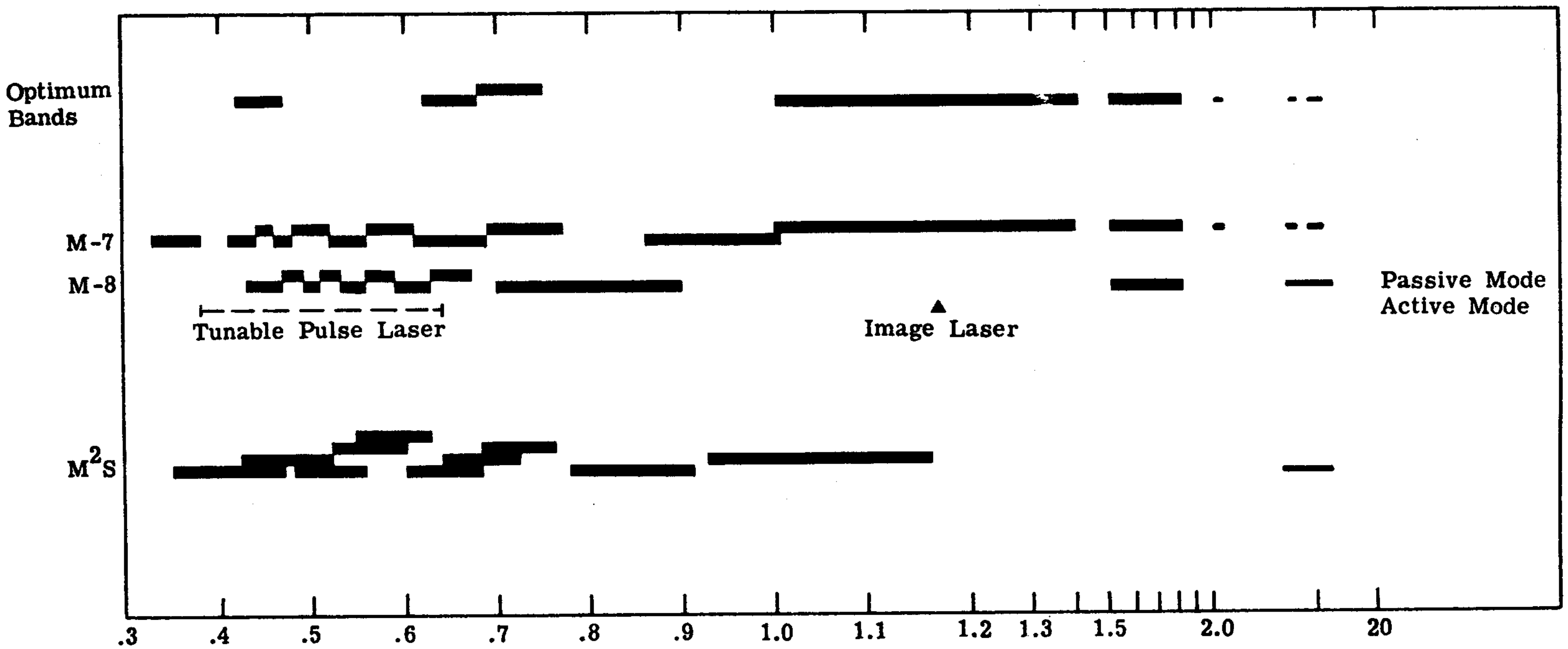


FIGURE 27. COMPARISON OF OPTIMUM SPECTRAL BANDS FOR VEGETATION ANALYSIS WITH THOSE OF THE M-7, M-8, AND M^2S SCANNERS.

inventories. For comparison the M^2S scanner spectral bands are shown.

In general, the ERIM scanners have narrower spectral bands which do not overlap. In the M-8 scanner we also have two "active" bands; by this we mean two spectral bands that detect radiation reflected from terrain that was illuminated by two lasers which are part of the scanner system. The development of the "active" scanner promises to be a major breakthrough in multispectral remote sensing applications and it is unfortunate we did not have the opportunity to use it in this study. In contrast, the M^2S scanner bands are wider and overlap more. All three sensors have adequate spectral coverage for vegetation mapping.

Although it doesn't cost significantly more to collect many bands of data, when it comes to data processing, every additional channel substantially increases computer time. Thus, we want to minimize the number of spectral bands of data we analyze. By the same token, the bands we use should be the ones which offer the greatest potential for spectral discrimination between scene classes.

One way of determining which channels to use is to compare the probability of misclassification between the spectral signatures of various scene classes using different combinations of channels. This was done twice in this study: once at the beginning of Phase II, to identify a subset of channels (See Table 3) to use on MIDAS, and again, for the Cape Yakataga unsupervised recognition processing (See Table 4). In the first case, only reflected channels were considered; in the second case, the thermal band was also considered.

The results of these analyses tell us two things. First, that very little improvement in expected classification accuracy is gained using more than four channels of data (See Figure 28); and, second, that all three major, spectral regions (visible, NIR and thermal IR) are important in the discrimination of the materials that make up the coastal Alaska environment.

In Figure 29 curves showing the relative signal in each channel from

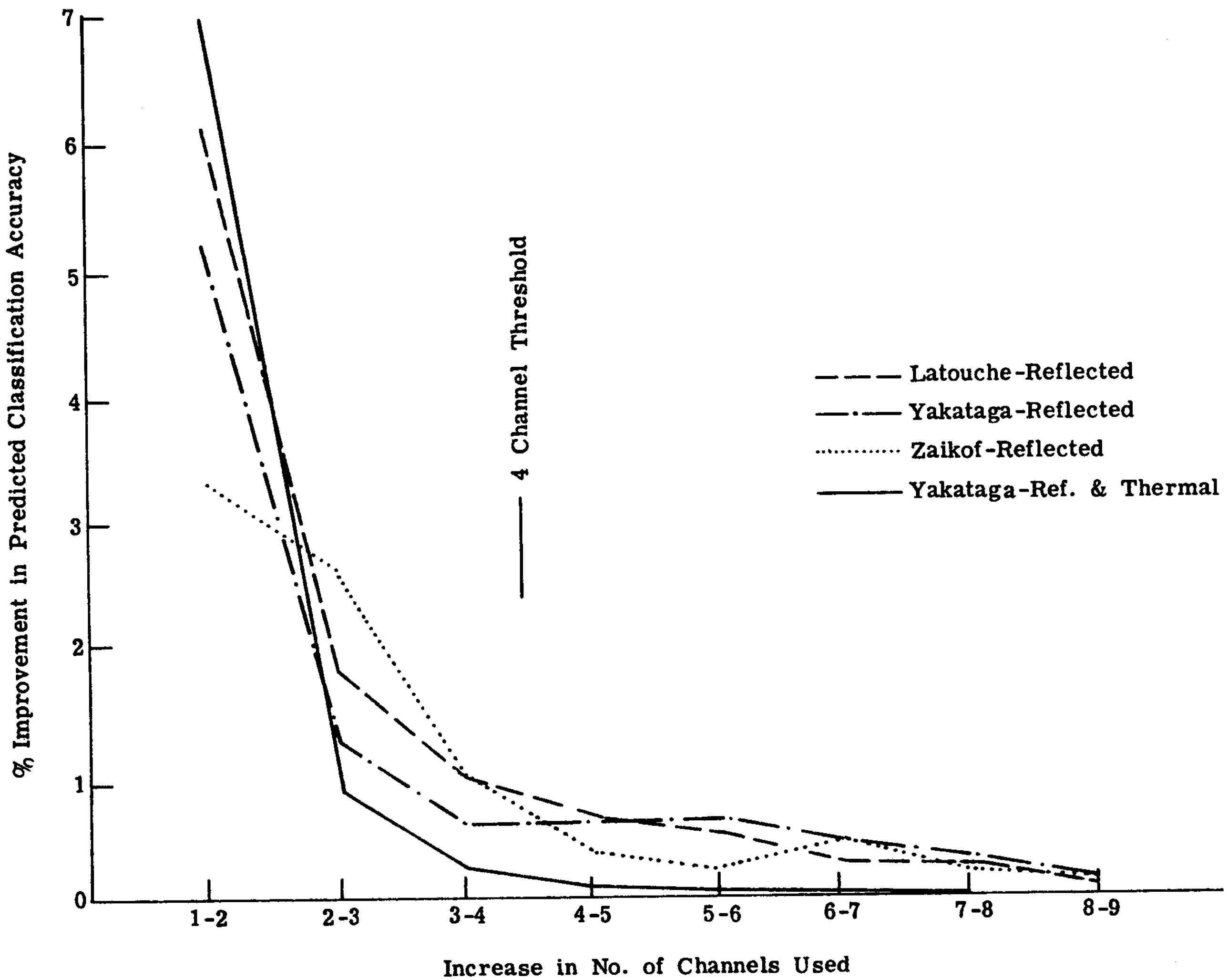


FIGURE 28. EXPECTED RECOGNITION PERFORMANCE INCREASE AS A FUNCTION OF ADDING SPECTRAL BANDS.

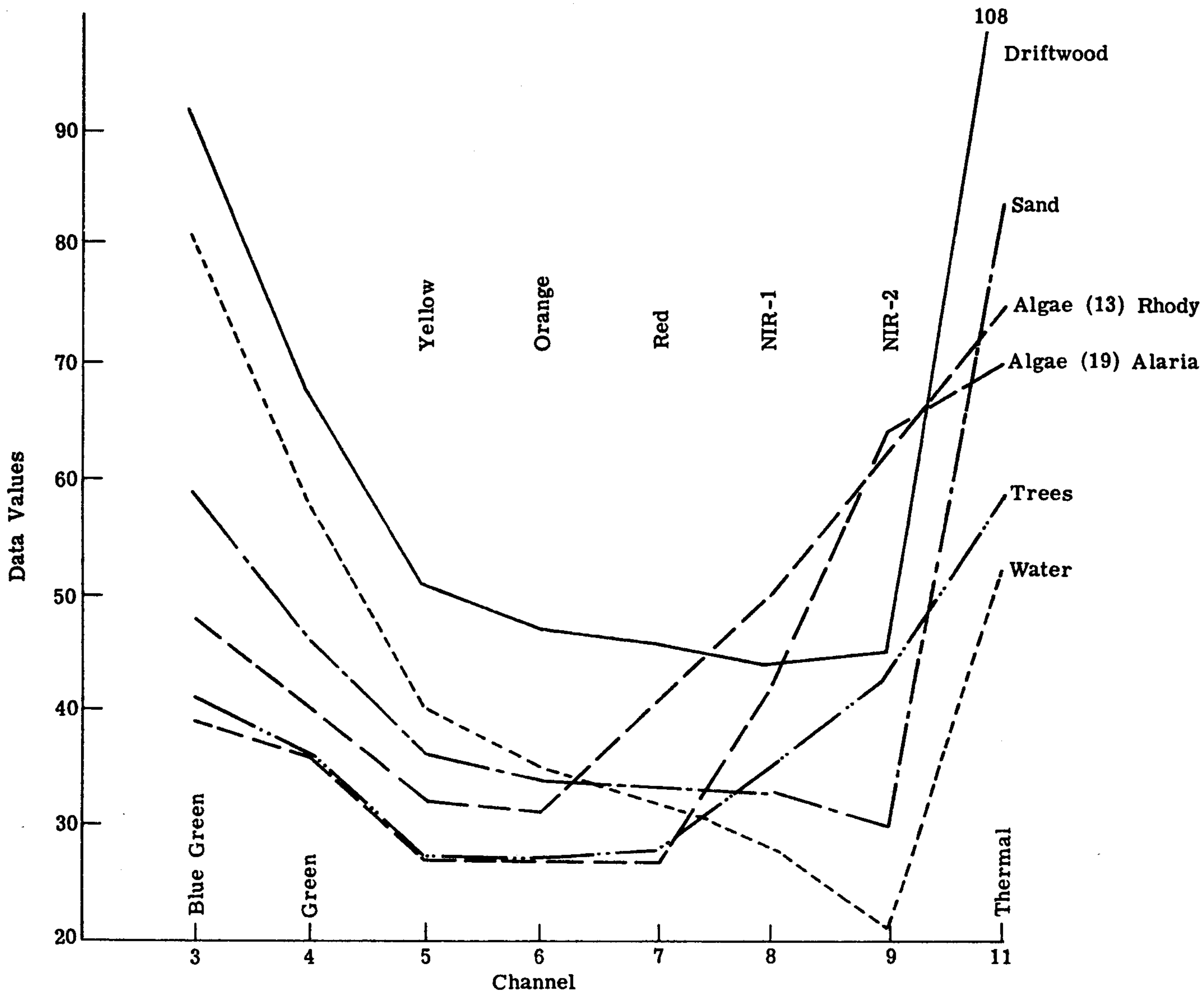


FIGURE 29. REPRESENTATIVE SPECTRAL SIGNATURES USED IN THE UNSUPERVISED CLASSIFICATION OF CAPE YAKATAGA.

representative scene classes illustrate the basis for our conclusions regarding the optimum number and placement of channels for discrimination. Beginning in the visible portion of the spectrum (channels 3-7) we see that non-living things are bright, compared to vegetation which is generally less reflective. One exception to this rule is the higher red reflectance of one of the algae signatures. This anomaly could be due to several things, contamination of the algae signature by a bright rock background, or perhaps the algae contains pigments especially reflective in this region (i.e., this may be the signature of a red or brown species of algae).

In the near-infrared region (channels 8 and 9) everything behaves as expected: the vegetation reflects highly, minerals reflect intermediate and water falls off to nearly zero reflectance. Out in the thermal region the non-living things show the effects of solar heating most dramatically, while the two types of vegetation display differential rates of transpiration. Water is, of course, the coolest thing in the scene. To summarize the reflectance patterns just described we have used the simple technique shown in Table 8.

TABLE 8

SIMPLIFIED SPECTRAL SIGNATURES OF COMMON MATERIALS FOUND IN THE CAPE YAKATAGA DATA SET

Material	Visible	Near-Infrared	Thermal
Driftwood	H*	M	H
Sand	M	L	M - H
Algae	L	M - H	M
Trees	L	M	M - L
Water	H	L	L

* Average Signal Response

H= High M= Moderate L= Low

With these reflectance relationships in mind, now is a good time to explain some differences in apparent recognition performance between some of the maps. Starting with Zaikof Bay, one thing we had trouble with there is recognition of the bare rock zone. Why we would have trouble with this is unclear when we look at Figure 7, because the rock is bright and we would expect it to have a relatively high reflectance in the visible and near-infrared regions. Yet, in the recognition maps (Figures 8, 9 and 12) the rock zone is confused to varying degrees with water. One possible explanation for this is that when data collection occurred two weeks after the photo was taken, the tide was not as low, and perhaps the rock zone was not completely dry; maybe even tidepools were present. (See Fig. 7). The signal received by the scanner from this region would then be a composition of dark rock and shallow water reflectance. This, in fact, is the type of reflectance signal we found to be characteristic for much of this area. Inclusion of the thermal band would eliminate this confusion because the heating effect of the sun would cause even the tidepools to be warmer than the ocean water.

Another thing we noticed was that actually a range of signatures was required to totally map each scene class. For example, to map a simple material like sand, it required training samples of wet sand and dry sand, coarse sand and fine sand, light colored sand and dark colored sand, and all the combinations of these that exist. The same is true of water. Classified as water are such diverse spectral conditions as deep water, shallow water, surf, tidepools and small streams. The existence of such a range of conditions, it should be obvious, place a considerable burden on those who choose to use supervised training set selection. It means a training set must be located for each and every condition exhibited by a scene class if the computer is to be adequately trained. In contrast, this is largely done automatically by clustering, and represents one of the major advantages of the unsupervised recognition processing approach.

With regard to the specific spectral bands that were found most useful in this study we can make the following remarks. Among the reflected bands, we found the single most useful band to be the second near infrared channel; the second most useful band was the green channel; then came the first near-infrared band, followed in fourth position by the yellow band. In the single study in which the thermal band was considered, it replaced the first near-infrared band as the third most useful channel. In summary then, for this study, we found the usefulness of channels to be the following:

TABLE 9

OPTIMUM SPECTRAL BANDS FOR ALASKA COASTLINE INVENTORY

Utility Rating	Spectral Region(m)		Channel No.	S/N
1	NIR-2	0.725-0.915	9	1
2	green	0.520-0.600	4	5
3	thermal	or NIR-1	8, 11	6, 4
4	yellow	8.14, 0.680- 0.760 0.540-0.640	5	2

Another factor that will seriously influence the usefulness of a given channel for spectral discrimination is its S/N ratio. It is thus not surprising that the channels selected are those with very high S/N ratios, as indicated by the relative ratings included in the table above taken from Table 2. The question of S/N may explain why the red band was not selected as a useful channel, as one might expect; the red band had one of the worst S/N ratios of any of the channels.

Briefly, then, it appears that if one had a scanner with only four spectral bands, it would be possible to achieve the performance levels achieved in this study if they (1) had good S/N ratios, and (2) were placed so that there were two in the visible part of the spectrum (one green and one orange or red), one in the near-infrared part of the spectrum (centered around 1.0 μm) and one in the thermal region.

5.3 EVALUATION OF DATA PROCESSING SYSTEMS AND DATA DISPLAYS

In this section, first we identify the important characteristics of a data processing system that make it either well-suited or ill-suited to handling a large data reduction task like the one posed by the hypothetical inventory task described earlier; then, we look at the role of the biologist in the total scheme of data processing and discuss how to best use the talents of such an individual; finally, we examine different types of data and information displays in an effort to find out what is the best way to get maximum information transfer.

5.3.1 BATCH MODE VS INTERACTIVE MODE

The enormity of the hypothetical coastal survey proposed in Section 5.1.3 does not really hit home until one actually calculates the amount of data that will be processed, and compares it to what is routinely done. For example, the amount of data we considered processing digitally (200 flight lines miles) is equivalent (on a number of channels x pixels basis) to 45 frames of Landsat data. Since Landsat was launched in 1973, probably fewer than 800 frames have been digitally processed.

The next thing that hits one, as the data processing is costed out, is that it is simple data transport that takes all the time and costs all the money; every time one does an operation on the data either 80 CCT's or 45 Discs must be loaded and unloaded. The time actually spent processing the data by the computer is trivial in comparison. Furthermore, it takes so long to move the data on a general purpose, time-sharing computer that the load must be spread out over a period of days to keep other users happy. As a result, the question of which computer can do calculations becomes almost irrelevant. The real question is: who has a cheap computer!? Of course, fast <u>and</u> cheap is the most desirable type of computer.

When it comes to choosing between batch mode or interactive mode for processing there appears to be no significant advantage to either system, except in the area of visual displays which we will discuss later. Typically an analyst runs a job, gets the results and then goes away to scratch his head and think about what to do next. Rarely is the next step immediately obvious, so the ability to interact instantaneous with the computer is of little value.

A more important characteristic of a data processing system that should be considered is the state of its software. All software should be compatible and error checking routines should be standard. This will prevent something happening during data processing that will result in an unreadable tape or loss of data. The software should also be designed to keep track of data in terms of scenes, channels, multiple-reels and completed operations, to reduce the analyst's bookkeeping requirements. Of course, full documentation of all program variables and algorithms should be considered essential. Suprisingly, few such software systems exist for multispectral data processing.

5.3.2 THE ROLE OF THE BIOLOGIST

In our opinion the person best qualified to supervise the processing of remote sensing data is an individual cross-trained in <u>three</u> different fields. In order of decreasing emphasis, these are: radiation-physics and computer technology. Neither an engineer nor a pure biologist will do as good a job as such an individual, all other things being equal. This is not to say that we think the biologist plays an insignificant role; quite the contrary. Actually, the biologist has the most important role; i.e., defining the project's purpose and objectives. But once these are done, the overall technical effort should be placed under the direction of a remote sensing specialist. Then, during the course of a project, the biologist can be called on only as his (or her) expertise is required. Such occasions would logically be (1) during ground truth acquisition; (2) during signature analysis; and (3) during recognition performance evaluation. The biologist's first-hand knowledge of the site and conditions is indispensable to doing a good job of these operations, but to be used most effectively it must be properly coordinated and directed.

For example, not just any data must be gathered during ground truthing, certain kinds of information are essential to good data processing. For example, in addition to species of vegetation, it is desirable to know foliage shape, leaf area index, leaf orientation, background color, background composition, the amount of shadow in the canopy, slope and aspect of the substrate and illumination conditions during overflight.

Similarly when it comes time to analyze signatures modeling the bidirectional reflectance conditions which provided the signals under analysis, it takes someone familiar with target-radiation interactions. Without a good understanding of vegetation canopy reflectance, interpreting spectral signatures would simply be a hit-or-miss affair, and the consequences of poor results too costly to allow this risk.

Finally, it is essential that the biologist be involved in determining the accuracy of classification that has been performed. The main reason for this is to convince the biologist that the results are good and can be relied on. Similarly, he will know first-hand the limitations of the results. This familiarity is essential in providing the biologist with enough confidence in the product to insure that it will be useful for decision making.

In brief, then, we visualize the role of the biologist as a changing one during the course of a project. Initially, the biologist identifies the task and specifies what results are needed. Then the remote sensing specialist designs the project and supervises its progress, including directing the biologist in ground truth acquisition and utilizing his knowledge in signature analysis. In these latter functions the biologist fulfills a service role. Finally, near completion of the project, after the remote sensing specialist and the biologist have jointly assessed performance results, the biologists' role changes again to that of the user of the results, making decisions on the basis of what has been learned.

5.3.3 DATA DISPLAYS

The one area of computer processing of remote sensing data where the interactive mode is desirable is in the production of maps, whether for computer training or recognition. The ability to generate maps quickly and cheaply is a great asset. Furthermore, these maps should have several characteristics. For example, the pixel size should be small enough to produce photo-like images, so that the eye can integrate large enough areas to identify important patterns. The value assigned each pixel (either recognition class or signal brightness) should be able to be made discrete, e.g., by the use of a color or symbol. Specific pixels should also be georeferenceable.

In this study, two data display modes were used: the alpha numeric type graymap made by computer lineprinters, and the color maps made by ERIM's ink jet printer. In all situations but one, the ink jet maps are a superior product. This one case was the identifying line and print numbers of training set pixels; the ink jet maps do not have rulers printed out in their borders like line printer maps do. This problem can be circumvented by using a electronic cursor to pick out the corners of the training sets on a CRT image of the map, but this is sometimes inconvenient. Nevertheless, we think ink jet color maps are a major breakthrough in remote sensing data display for both analysis purposes and final products.

The ability to make such maps quickly in the signature analysis phase of a project is a real time-saving advantage and undoubtedly improves the quality of the analysis. Subjective anlaysis so often depends on identifying subtle things which in turn are only brought out by effective display, resulting from sequential refinement. This process of "zeroing in" on the identification of the subtle patterns in a scene that are needed to accurately locate training sets or evaluate accuracy should not be underestimated in its importance. It is the only way good training sets can be manually located, and without good training sets it is impossible to get good recognition.

The other type of data display that is normally associated with remote sensing data is statistics. For this type of project the statistics we are interested in is the ground area of the scene covered by each scene class. Producing such statistics from remote sensing data is the forte of a computer and the bane of humans.

Conceptually, the process is simple: Because remote sensing data collection geometry is known, we can assign to each pixel the area it represents on the ground. Then, after classification, when we know what scene class each pixel belongs to, we simply tally the number of pixels in each class and multiply this figure by the area each pixel represents. The result is the ground area of the scene occupied by each scene class.

The procedure for calculating such statistics with airborne MSS data involves only one additional step: geometric rectification. In this step we correct for the fact that pixel size varies along the scanline as the scanner looks out to the side (see Figure 30). In uncorrected scanner data, pixel size at nadir is nominally 2.5 ft.sq. At the edge of a scanline, the IFOV is roughly 4 ft. square. Obviously then in uncorrected data, a pixel of a given scene class at the edge of a scan line does not represent the same relative proportion of the scene as a pixel of the same scene class at nadir. To equalize pixel size is a simple matter, however, and a cosine function is applied across a scan line, which in effect compresses pixels at the edges of the scan line until they are the same size as those at the nadir. Now, once all

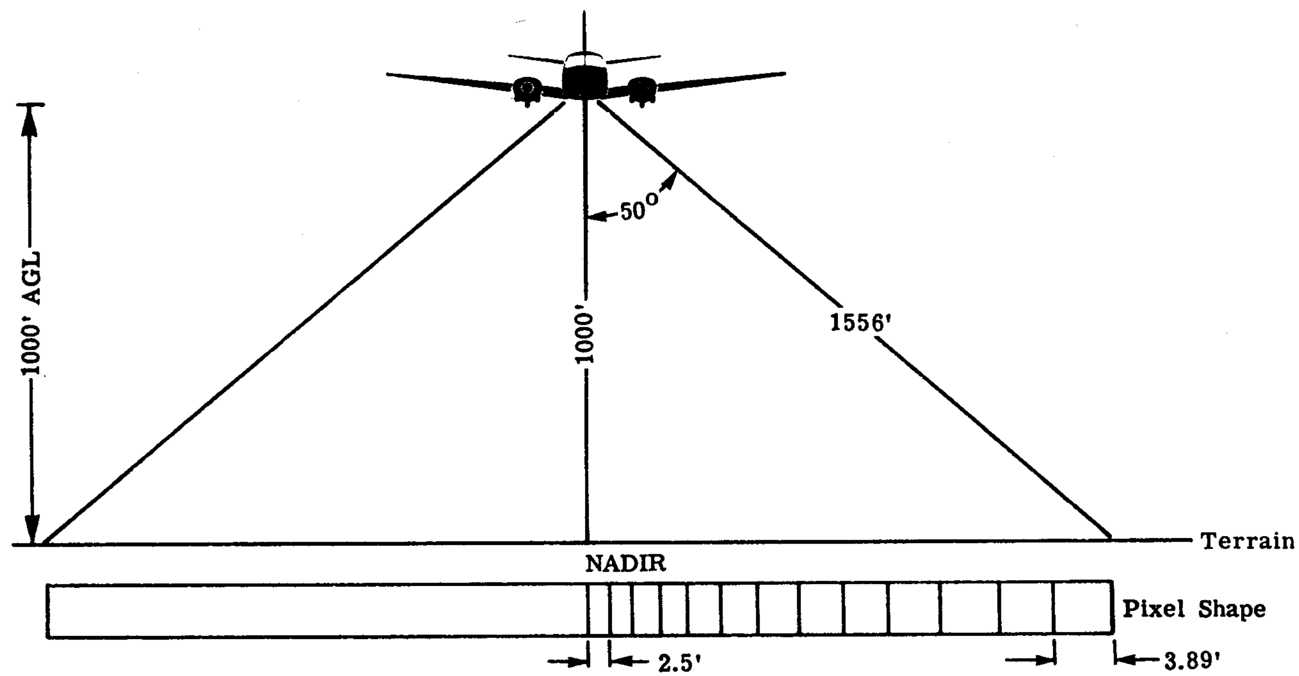


FIGURE 30. SCAN ANGLE GEOMETRY OF AIRCRAFT MSS DATA.

the pixels are the same size, it is a simple matter to tally up their number by scene class and multiply by the area factor to get the desired inventory statistics.

To illustrate this principle the statistics associated with the maps for the Phase I processing are included in Appendix B.

In the following chapter we summarize the conclusions arrived at based on the analyses discussed in this chapter.

6.0
CONCLUSIONS

The following conclusions have been reached on the basis of the work undertaken during the course of the project:

- It is possible to identify vegetation in the intertidal zone from other scene classes (e.g., water, sand, rock, and driftwood).
- It appears possible to further separate vegetation into broad spatial zones representing either species of algae or species associations, or simply vegetation density classes (which may correlate with species groups).
- It is possible to collect useable data under overcast illumination conditions.
- Clustering techniques represent the most effective way to extract training signatures.
- A minimum of four spectral bands is needed to achieve the recognition performance levels demonstrated in this study.
- Optimum spectral bands include two channels in the visible part of the spectrum (green and red), one in the near-infrared region (near 1.0μm) and one in the thermal region.
- Special purpose computers designed specifically to handle remote sensing data can reduce processing costs.
- Concise visual displays of results are essential for signature analysis, recognition performance evaluation, and final products.
- Optimum project design and implementation are best left to a specialist trained in remote sensing data handling and reduction with a strong background in biology and radiation-physics.

7.0
RECOMMENDATIONS

We have two types of recommendations. Type 1 relates to improving classification accuracy. Type 2 relates to reducing cost.

Type 1 Recommendations

If recognition accuracies prove to be lower than desired, more sophisticated newly developed training set selection techniques would be evaluated:

- o test clustering techniques which employ spatial relationships between pixels as well as spectral characteristics.
- o Test classification rules that base recognition on the spectral characteristics of surrounding pixels in addition to individual pixels.

Type 2 Recommendations

These deal with finding ways to reduce the costs associated with data collection and processing:

- o Evaluate the possibilities of mapping some areas at coarser spatial resolution. If you fly higher you can cover more ground faster, and there are less pixels to process. This gives a first stage sample of the distribution.
- o Evaluate the use of finer spatial data collected on a sampled basis supported by ground measurements to provide classification accuracies for the multistage survey.

REFERENCES

1. C.T. Wezernak, D.R. Lyzenga, and F.C. Polcyn, 1974. Cladophora Distribution on Lake Ontario (IFYGL). EPA-660/3-74-028 National Environmental Research Center, USEPA, Corvallis, Oregon.

2. Tanis, F.,(in press)

3. Polcyn, F.C., D.R. Lyzenga and E.I. Marinello. 1977. Investigation of Intertidal Zone Mapping by Multispectral Scanner Techniques, ERIM Report No. 123200-1-F.

4. Sadowski, F. and J. Sarno. 1976. Forest Classification Accuracy as Influenced by Multispectral Scanner Spatial Resolution. ERIM Report 109600-71-F.

5. American Society of Photogrammetry. 1968. Manual of Color Photography. Chuck Falls, Virginia.

6. R.E. Turner, Radiative Transfer in Real Atmospheres, Report No. 190100-24-T, Environmental Research Institute of Michigan, Ann Arbor, Michigan, July 1974.

7. G.H. Suits, The Calculation of the Directional Reflectance of a Vegetative Canopy, Remote Sensing of Environment, Vol. 2, 1972, pp. 117-125.

APPENDIX A

The four sheet flight log contained in this appendix describes the data acquisition sequence for this project. Five passes were flown at each of the three study sites, Zaikof Bay, Latouche Island and Cape Yakataga. Scanner data was collected on every pass, but natural color photography (Kodak SO-397) was collected only once per sequence, except at Cape Yakataga where coverage was obtained during all 500 ft. altitude overpasses.

As part of a calibration procedure for the scanner data, overpasses were also made of a set of these panels of known reflectance 40 ft. x 20 ft. in size. This data can now be used as a reference for calculating the minimum percent reflectance that the scanner could detect under the illumination conditions and instrument configuration that prevailed during data collection. The panel overflights were made at the Cordova airfield on June 26th.

M^2S FLIGHT LOG

DATE 6-9-76, 6-26-76, 6-27-76 , 6-28-76

OPERATOR Haeske
A/C N41WA

FLIGHT NO. ______ MISSION ID. ERIM / Alaska TAPE NO. 1 FILM TYPE(S) SO-397

FILTER(S) Hase 500/5.6

CAMERA(S) Hassalblad

PILOT Byers

CO-PILOT ______

RECORDER	1	2	3	4	5	6	7	8	9	10	11	12	13	14
SCANNER	1	2	3	4	5	6	7	8	9	10	11			
CAL HIGH											070			
CAL LOW											233 296			

070 = 35°C
233 = 10°C
296 = 5°C

PAGE 1 OF 4

RUN	LINE ID	T.O.T.	RUN TIME Min	G.S.	A.G.L.	MAG. HDG.	ACCUM COUNT	FRAME COUNT	IV	S/S	DIAL SET	MISSION NOTES
1		1020	2.0	180	1.3K	160				70	668	Test Flight 6-9-76 Bremerton, Wash.
2		1245	1.0	140	2.5K	210				70	668	VHF TX During Run Test Flight 6-26-76 Anchorage, Ak.
3	1	0708	.38	140	1.5K	195	0 7	7	6	70	668	6-27-76 WX-Very Overcast & Dark Zaikof Bay
4	2	0712	.45	100	1K	195				70	668	Thermal May Be Clipping Negative
5	3	0715	.50	100	1K	195	17		5	50	450	
6	4	0720	.40	100	1K	120	23		5	70	668	
7	5	0723	.40	90	400	195				70	668	
8	1	0745	.50	150	1.5K	120	32		6	70	668	Latouche Low Black Body 296
9	2	0750	1.00	100	1K	120				70	668	
10	3	0753	1.00	100	1K	120				50	450	
11	4	0756	.45	100	1K	010	42		5	70	668	
12	5	0759	1.00	100	400	120				70	663	
13		0809	.50	100	1K	030	47		5	70	668	Needle

M^2S FLIGHT LOG

(cont'd)

DATE 6-27-76, 6-28-76 OPERATOR Haeske

FLIGHT NO. ______ MISSION ID. ERIM/ Alaska TAPE NO. 1 FILM TYPE(S) SO-397

FILTER(S) Hase

CAMERA(S) Hassalblad

PILOT Byers

PAGE 2 OF 4 CO-PILOT ______

RECORDER	1	2	3	4	5	6	7	8	9	10	11	12	13	14
SCANNER	1	2	3	4	5	6	7	8	9	10	11	-	-	-
CAL HIGH											070			
CAL LOW											296			

RUN	LINE ID	T.O.T.	RUN TIME	G.S.	A.G.L.	MAG. HDG.	ACCUM COUNT	FRAME COUNT	IV	S/S	DIAL SET	MISSION NOTES
14	1	0845	.40	130	1.5K	090	8		6	70	668	6-27-76 Panels on Gravel at Cordova Airport
15	2	0848	.40	100	1K	090				70	668	
16	3	0850	.40	100	1K	090	14		?	50	450	
17	4	0852	.40	100	1K	180				70	668	
18	5	0855	.40	100	400	090				70	668	
19	1	0800	.45	120	1.5K	170	8		6	70	668	WX-Overcast Some Thin Spots Cape Yakataga Gyro Caged
20	1	0804	.50	120	1.5K	165				70	668	
21	2	0808	.50	200	1K	165				70	668	
22	3	0811	.50	100	1K	165				50	450	
23	4	0815	.50	100	1K	075	17		5	70	668	
24	4	0818	.50	100	1K	255				70	668	Opposite Direction Same as above Closer to Shore
25	5	0821	.50	100	400	165	26			70	668	Manual Pictures
26		1410	1.15	100	1K	285	000 19			70	668	Nochek Gyro Caged
27		1413	1.05	100	1K	285				70	668	Nochek Same As Above Uncaged

614

M^{2}S FLIGHT LOG

(cont'd)

DATE 6-28-76 OPERATOR Haeske

FLIGHT NO. ______ MISSION ID. ERIM/ Alaska TAPE NO. 1 & 2 FILM TYPE(S) SO-397

FILTER(S) Hase

CAMERA(S) Hassalblad

PILOT Byers

PAGE 3 OF 4 CO-PILOT ______

RECORDER	1	2	3	4	5	6	7	8	9	10	11	12	13	14
SCANNER	1	2	3	4	5	6	7	8	9	10	11			
CAL HIGH											070			
CAL LOW											296			

RUN	LINE ID	T.O.T.	RUN TIME	G.S.	A.G.L.	MAG. HDG.	ACCUM COUNT	FRAME COUNT	IV	S/S	DIAL SET	MISSION NOTES
28		1415	.45	100	1K	240	27		5	70	668	Made Extra Run Over Rocks 9 Pictures Porpoise Rocks 6-28-76
29		1425	.45	100	1K	210	36 / 37		5	70	668	Sun Glint Seal Rocks
30		1427	.30	100	1K	190	43		5	70	668	Sun Glint Seal Rocks
31		1430	.30	100	1K	010	50		5	70	668	Sun Glint Small Rocks
32		1432	.30		400	190	56		5	70	668	Sun Gline Seal Rocks
33		1449	.55	130	1.5K	040	60		6	70	668	Wooded Isle
34		1453	1.05	130	1.5K	040	74		6	70	668	Wooded Isle
35		1455	.30	100	1K	070	79		6	70	668	Fish Isle
36		1509	.30	100	1K	190	87		6	70	668	Needle
37		1511	.30	100	400	010	90		6	70	668	Needle
38		1646	2.45	170	10K	210				35	250	Start Tape #2 Montaque to Green is Whale △ , High Alt.
39		1700	2.30	100	1K	030				70	668	Green to Montique Whale △ , Line #1
40		1703	4.54	100	1K	280				70	668	Montique to Seal is #2
41		1709	4.54	100	1K	140						Seal to Green is #3 Sun Glint

615

M²S FLIGHT LOG

(cont'd)

DATE 6-28-76

OPERATOR Haeske

FLIGHT NO. ______ MISSION ID. ERIM / Alaska TAPE NO. 2 FILM TYPE(S) SO-397

FILTER(S) Hase

CAMERA(S) Hassalblad

PILOT Byers

PAGE 4 OF 4

CO-PILOT ______

RECORDER	1	2	3	4	5	6	7	8	9	10	11	12	13	14
SCANNER	1	2	3	4	5	6	7	8	9	10	11			
CAL HIGH											070			
CAL LOW											297			

RUN	LINE ID	T.O.T.	RUN TIME	G.S.	A.G.L.	MAG. HDG.	ACCUM COUNT	FRAME COUNT	IV	S/S	DIAL SET	MISSION NOTES
42	1	1735	.30	150.	1.5K	090		2		70	668	Manual Pictures Panels
43	2	1739	.40	100	1K	090				70	668	
44	3	1741	.40	100	1K	090				35	250	
45	4	1746	.30	100	1K	180				70	668	
46	5	1749	.30	100	400	090		3		70	668	Manual Pictures

APPENDIX B

The statistics presented here were generated automatically by computer for the Phase I processing results. They accompany the indicated maps.

ZAIKOF BAY

Run 7

Map: Figure 8

LEVEL	SCENE CLASS	COLOR	NUMBER OF PIXELS	AREA (m^2)
1	Algae 1A	light red	2259	4489
2	Algae 2A	olive brown	23439	4666
3	Algae 3A	dark green	11482	2287
4	Algae 4A	light green	24534	4885
5	Algae 5A	orange	15720	3130
6	Rock 1A	dark gray		
7	Rock 2A	black		
8	Grass	yellow		
9	Trees	light orange		
10	Algae 6A	light purple	21131	4207
11	Water	blue		
255	Unclassified	white		

The average pixel = 2.14 ft^2 or 0.20m^2

TOTAL AREA

pixels = 437,660 @ 0.20 m^2/pixel

Total Area = 8.7^{1nd}

LATOUCHE ISLAND

Run 9

Map: Figure 14

LEVEL	SCENE CLASS	COLOR	NUMBER OF PIXELS	AREA (m^2)
1	Algae 1C	light red	22258	12304
2	Algae 2C	olive brown	15987	8837
3	Algae 3C	dark green	14251	7878
4	Algae 4C	light green	10693	5911
5	Algae 5C	dark orange	36872	20382
6	Algae 6C	violet	8864	4900
7	Algae 7C	dark red	16939	9363
8	Algae 8c	light blue	18407	10175
9	Algae 9C	black	12237	6764
10	Water	blue		
11	Trees	light orange		
12	Grass	yellow		
13	Rock	gray		
255	Unclassified	white		

The average pixel = 5.95 ft.^{2} or 0.55m^2

TOTAL AREA

pixels = 300,600 @ 0.55m^2/pixel

Total Area = 16.6 1nd

CAPE YAKATAGA

Run 21

Map: Figure 18

LEVEL	SCENE CLASS	COLOR	NUMBER OF PIXELS	AREA (m^2)
1	Algae 1B	light red	15761	8712
2	Algae 2B	olive brown	14389	7954
3	Algae 3B	dark green	5862	3240
4	Algae 4B	light green	18402	10172
5	Algae 5B	dark orange	9828	5433
6	Algae 6B	violet	12380	6843
7	Algae 7B	dark red	33773	18669
8	Rock 1B	gray		
9	Algae 8B	black	43470	24029
10	Rock 2B	light blue		
11	Algae 9B	light orange	18238	10081
12	Water	blue		
13	Grass	yellow		
255	Unclassified	white		

The average pixel = 5.95 $ft.^2$ or 0.55 m^2

TOTAL AREA

pixels = 259,201 @ .55 m^2/pixel

Total Area = 14.3 2nd

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