Exxon Valdez Oil Spill
Restoration Project Annual Report

Experimental Harlequin Duck Breeding Survey

Restoration Project 94427
Annual Report

This annual report has been prepared for peer review as part of *Exxon Valdez* Oil Spill Trustee Council restoration program for the purpose of assessing project progress. Peer review comments have not been addressed in this annual report.

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Study History: Restoration Project 94427 continues the harlequin duck (*Histrionicus histrionicus)* studies begun by the Alaska Department of Fish and Game in 1992 with Bird Study Number 11 (Injury Assessment of Hydrocarbon Uptake by Sea Ducks) and Restoration Study Number 71 (Harlequin Duck Restoration and Monitoring). An estimated 451 harlequin ducks died in PWS as a direct result of oil exposure following the spill. The preceding studies attributed the spill to causing a decline in the 'resident' population of harlequin ducks inhabiting heavily oiled areas of western PWS and to declines in reproductive success of birds surviving or avoiding initial exposure. Little information, however, was collected on sex and age composition, seasonal population shifts, or proportions of paired birds, data necessary for examining the health of a population. The objectives of this project include developing age and sex criteria for harlequin ducks that can be used to classify the composition of the spring (breeding) population, designing a sampling scheme that can be used in future EVOS restoration activities to reliably estimate the number of breeding pairs, and conducting shoreline brood surveys to measure productivity of harlequin ducks in oiled areas of western PWS.

Abstract: In response to declines in harlequin duck numbers following the *T/V Exxon Valdez* oil spill in 1989, surveys were conducted in May and June in western Prince William Sound to classify harlequin ducks by sex, age, and breeding status. Age and sex classifications were based on plumage patterns. Males were divided into one of three age classes, first-year, second-year, and adult. Females could not be aged. The population increased during spring as the number of males increased from 64% of the population in late-May to 87% by late-June. Simultaneously, the number of females and pairs declined. Subadult males comprised almost 15% of the male population in late June. Brood surveys and molting population surveys were conducted from late-July to early September. An average of 369 km of shoreline was surveyed during each of the first three survey periods. Only one brood was observed. Molting populations increased throughout the fall surveys. Males molted before females. The percentage of males in the total population declined from a high of 81% at the end of July to a low of 54% in early September.

Key Words: harlequin duck, *Histrionicus histrionicus,* oil spill, population monitoring, Prince William Sound, restoration, seaducks.

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EXECUTIVE SUMMARY

Harlequin ducks *(Histrionicus histrionicus)* occur year-round in intertidal and shallow, subtidal zones (nearshore waters) of Prince William Sound (PWS), Alaska. In 1989, large numbers of harlequin ducks died in PWS as a direct result of oil exposure following the *T/V Exxon Valdez* oil spill(EVOS). Post-spill studies report a decline in the number and productivity of harlequin ducks inhabiting oiled areas of western PWS. Continued decline in the harlequin duck population may result in a significant reduction or loss of this resource in PWS.

Harlequin duck population levels are sensitive to adult survival, breeding propensity (% breeding annually), and the number of breeding individuals. Sex and age composition of the population can influence these parameters. Unfortunately, pre- and post-spill surveys reveal little about the sex and age structure of harlequin ducks in western PWS. Lack of information makes it difficult to predict future trends in harlequin numbers. To accurately monitor population levels of harlequin ducks in western PWS, it is important to assess the structure and productivity of the population. Numbers, sex and age structure of the population, adult survival and annual production of young can be used as indicators of population growth or decline.

The objectives of this project are to conduct boat surveys of previously surveyed selected shoreline segments of western PWS during May and June to: (1) develop age and sex criteria for harlequin ducks that can be used to classify the composition of the spring (breeding) population; (2) design a sampling scheme that can be used in future EVOS restoration activities to reliably estimate the number of breeding pairs and the sex and age composition of the population; and (3) conduct shoreline brood surveys to measure productivity of harlequin ducks in oiled areas of western PWS.

Surveys were established in areas previously surveyed that were known to support harlequin ducks. Surveys were conducted from an open skiff within 100 meters of shore at a pace, course and distance that assured complete coverage of the survey area and maximized the opportunity to observe ducks. Ducks were counted and classified by sex, age, or breeding pairs.

Males were divided into one of three age classes, first-year, second-year, and adult. Females could not be aged. The population increased during spring as the number of males increased from 64% of the population in late-May to 87% by late-June. Simultaneously, the number of females and pairs declined. Subadult males comprised almost 15% of the male population in late June.

Brood surveys, (to measure productivity) and molting population surveys were conducted from late-July to early September. An average of 369 km of shoreline was surveyed during each of the first three survey periods. Only one brood was observed. Molting populations increased throughout the fall surveys. Males molted before females. The percentage of males

in the total population declined from a high of 81% at the end of July to a low of 54% in early September.

Criteria separating adult male and female harlequin ducks in spring are well documented. Adult males are in full nuptial or 'definitive alternate plumage' and we easily distinguished them from females and first-year males. Sexes can be separated during the spring and during the molt. There has been little previous work comparing the sex ratios of molting flocks.

The age at which harlequin ducks reach sexual maturity and attain adult plumage is uncertain. No studies with known age birds exist nor have plumage patterns coincidental with age been well defined for spring birds. We assume male harlequin ducks acquire definitive plumage in the third year of life. Our age categories should be considered a "working hypothesis" because no known age birds were used in its development. We could not separate females by age. The number and proportions of subadult birds can be used to measure recruitment and detect changes in productivity. For this to be useful in comparing populations, aging criteria must be standardized.

Population structure, distribution, and abundance of harlequin ducks changes within and among seasons. In spring the number of harlequin duck pairs decreased coincidental to an increase in the number of males and a drop in the number of females. This decrease in pairs represents a departure for breeding areas. Most subadult birds, males and females, remain along the coast until at least their third-year of life.

Males outnumbered females. Male-favored sex ratios have been reported in various studies of wintering harlequin ducks but few studies have looked at spring ratios in coastal areas. Males steadily increased from late-May to late-June; others have found similar trends. Male surpluses are reported from inland nesting areas. We expect a greater surplus in coastal areas because of the presence of coastal breeding males, non-breeding adult males, and non-breeding subadult males which do not migrate inland. Little information exists from other studies to compare ratios of subadults to adults. Densities increased throughout the fall as birds returned from breeding areas to molt. Molting birds exhibit site fidelity and are relatively stationary; therefore, molting populations may serve as the best measure of population trends.

There is little definitive pre-spill baseline data to adequately indicate the historical extent of coastal nesting and brood rearing in western PWS. Prior to the spill no inclusive brood surveys had been conducted for PWS but incidental observations were common. We saw no broods in oiled areas of western PWS. This lack of reproduction has been consistent since the spill, yet subadult birds are present in spring.

Low reproductive success of harlequin ducks in PWS since the spill should have resulted in changes in age and sex structure towards a greater proportion of adult males. Because we can classify males by age in spring, we can design repeat surveys that will document changes in abundance; distribution; number of breeding pairs; and age and sex structure of the population. The ratios and timing of these changes in population structure and abundance should be indicative of the current breeding behavior of the population. The ratio of subadult to adult males will serve as an index of recruitment, an indication of past breeding success.

If reproduction is continually low or absent, populations will decline if no immigration occurs. Harlequin duck production and post-breeding abundance can be documented by conducting repeat surveys in the late summer and fall during the post-nuptial molt. Seasonal changes in sex ratios and abundance will indicate current breeding behavior and comparing year to year changes in abundance will indicate population trends. Brood surveys will measure productivity. These parameters can be compared for populations of harlequin ducks inhabiting oiled and unoiled areas.

We developed field criteria, based on plumage characteristics, to classify male harlequin ducks into 3 age classes during spring. We also developed criteria to classify harlequin ducks by sex during breeding and molting periods. Surveys to detect seasonal changes in sex ratios indicated chronological events such as departure for breeding grounds, nest initiation, disbanding of paired ducks and arrival at molting areas. Brood surveys indicated low productivity.

We designed a sampling technique using fixed segments over broad regions to be surveyed repeatedly throughout the breeding season. Repeated surveys will allow for temporal (both annual and seasonal) and spatial comparisons of sex, age, and abundance of harlequin ducks comprising populations in oiled and non-oiled areas of PWS.

Annual monitoring of population structure and reproductive success of harlequin ducks will allow us to assess trends and suggest factors that limit recovery. This will provide a more reliable basis for restoration planning and be consistent with an adaptive management approach that allows more efficient allocation of efforts and enrichment of knowledge over time (e.g. for a long-term monitoring program).

INTRODUCTION

Harlequin ducks (*Histrionicus histrionicus)* occur year-round in intertidal and shallow, subtidal zones (nearshore waters) of Prince William Sound (PWS), Alaska (Isleib and Kessel 1973). In 1989, large numbers of harlequin ducks died in PWS as a direct result of oil exposure following the *T/V Exxon Valdez* oil spill (Ecological Consulting Inc. 1991, John Piatt, USFWS, pers. comm.). Post-spill studies report a decline in the number (Klosiewski and Laing 1994, Patten 1995, Patten et al. 1995) and productivity (Patten 1995, Patten et al. 1995) of harlequin ducks inhabiting oiled areas of western PWS. Patten (1995) and Patten et al. (1995) suggested the decline was the result of high initial mortality, continued ingestion of oil resulting in sub-lethal impairment of reproduction, and displacement to non-oiled areas. Detectable levels of hydrocarbons have been found in esophageal foods and tissues of harlequin ducks collected during 1989, 1990 and 1993 (Patten 1995, Patten et al. 1995). No conclusive evidence exists, however, for relating histological or physiological injury to oil ingestion by harlequin ducks. Unless monitored, harlequin duck numbers may continue to decline resulting in a significant reduction or loss of this resource in PWS.

Harlequin ducks are typical of other sea ducks in that they are relatively long lived, and exhibit delayed sexual maturity and low annual production (Goudie et al 1994). Thus, population levels are sensitive to adult survival, breeding propensity (% breeding annually), and the number of breeding individuals (Goudie et al. 1994). Demographic characteristics of the harlequin duck population can influence overall productivity. Therefore, we suggest age and sex ratios can be used as indicators of population growth or decline. To accurately monitor population levels of harlequin ducks in western PWS, it is important to evaluate the composition and productivity of the population. Unfortunately, pre- and post-spill surveys (Dwyer et al. 1976, Sangster et. al. 1978, Hogan and Murk 1982, Irons et. al. 1988, Hotchkiss 1991, Agler et. al. 1994, Klosiewski and Laing 1994, Patten 1995 and Patten et al. 1995) reveal little about the sex and age composition of harlequin ducks in western PWS. Lack of information makes it difficult to predict future trends in harlequin numbers. Additionally, little pre-spill information on productivity of harlequin ducks in western PWS makes comparisons with post-spill populations difficult. Prior to the spill no systematic brood surveys were conducted, however, incidental brood observations are common (Isleib and Kessel 1973, Sangster et. al. 1978, Oakley and Kuletz 1979). After the spill, only 14 harlequin duck broods were observed in areas surveyed during 1989 - 1993 (Patten 1995, Patten et al. 1995) suggesting that reproduction declined in harlequin ducks inhabiting oiled areas. We believe it is necessary to revisit areas where pre-spill observations of broods were made to determine whether productivity has increased since the initial decline.

OBJECTIVES

The primary objective of the study is to determine whether sex and age classes of harlequin ducks could be easily distinguished during shoreline surveys. We used diagnostic characteristics of plumage patterns described in the literature, and report new criteria developed during the study to separate age and sex classes of harlequin ducks. Additionally, we report on the feasibility of using videography and photography to produce instructional material for determining sex and age classes of harlequin ducks.

A second objective is to design a sampling scheme which can be used in future restoration activities. A standardized survey design and knowledge of population demographics will allow us to monitor trends in abundance, evaluate productivity, and estimate breeding chronology (e.g. nest initiation, molt) for harlequin ducks in PWS. Conducted annually, these surveys can index adult survival by monitoring long-term changes in the age structure of the population. Our sampling design also included surveying brood-rearing habitat, primarily on Green and Naked Islands, to document production of young in oiled areas of western PWS.

To be complete, we report on seasonal variation in the abundance, and sex and age composition of the harlequin duck population. Because this is a preliminary study, designed to establish methodologies for future work, we did not standardize sampling procedures before all surveys were completed. Therefore, our sampling effort and study goals varied among survey periods.

STUDY AREA and METHODS

A general description of the physiography, climate, oceanography, and avian habitats of Prince William Sound is described by Isleib and Kessel (1973). Our study area included shorelines of mainland, island and offshore rocks in western PWS from the north end of Culross Island, south to Jackpot Bay and east to Green Island (Fig. 1). Surveys were conducted along Knight Island, Applegate Island, Foul Bay, Main Bay, Eshamy Bay, Crafton Island, Chenega Island, Green Island, Channel Island, Montague Island, and Naked Island (Fig. 2). Surveys were conducted in areas previously surveyed by Patten (1995) and Patten et al. (1995), and known to support harlequin ducks.

Surveys were conducted from an open, 6m long skiff traveling at 2-20 km/hr. One full-time observer and a observer/boat operator continuously surveyed each survey segment using 10X binoculars. Surveys were conducted within 100 meters of shore at a pace, course and distance that assured complete coverage of the survey area and maximized the opportunity to observe ducks. Our distance from shore depended on light, weather and tide conditions. No surveys were conducted when wave height exceeded 60 cm.

Spring

Three survey periods were conducted between 25 May and 23 June, 1994. Each survey period lasted approximately 7 days and consisted of several survey segments. Not all segments were surveyed during each survey period, whereas some segments were surveyed twice. The largest count of ducks was used for comparative purposes when a segment was surveyed more than once during the same survey period.

Because the focus of spring surveys was to develop age and sex criteria, we did not map survey segments and duck locations, or calculate segment lengths. Therefore, we can not estimate harlequin duck densities for the spring-survey periods.

When harlequin ducks were observed, birds were classified to sex, and males were categorized by 1 of 3 age classes based on plumage patterns (1st yr., 2nd yr., adult). First and second year males were considered sub-adults (Terres 1980). We used observations of museum study skins, photographs, published literature and personal communications in developing age and sex criteria. An adult male and female were considered a pair when they were physically closer to one another than either was to the next closest duck, either while swimming, roosting or flying. For large groups (>10 birds) of harlequin ducks, we found it easiest to differentiate age and sex classes when roosting flocks where initially observed before they flushed. From a vantage point (offshore rock, beach) we observed ducks with a high resolution (60mm objective lens, 20-60 power zoom) spotting scope mounted on a tripod. Ducks were observed from close distance when we were able to conceal ourselves from view. Flocks with <10 birds could often be approached slowly in the skiff and observed with 10X40 binoculars. Video and still photography could only be accomplished from close distances, usually from a blind. Both procedures were time consuming and required appreciable effort. Photographic opportunities were limited by poor weather, inadequate lighting, and maintaining a sharp focus on moving birds. High resolution photographs were useful in developing age criteria.

Fall

Five survey periods were conducted from 23 July through 9 September 1994. Segments surveyed in the spring were repeated and additional sites were included to survey brood rearing habitat and known molting areas. The duration and coverage varied among fall-survey periods. Survey segments were mapped and shoreline lengths were calculated from The Alaska Department of Natural Resources PWS_ESI Arc Info GIS database. Shoreline length for some small islands were calculated using the U.S. Forest Service CNFSHORE Arc Info GIS database.

Harlequin duck observations were mapped and birds were classified by sex only, because basic plumage patterns prohibited aging males. Broods were identified by the presence of down and behavior. Ducklings were aged according to Gollop and Marshall (1954). Harlequin ducks were considered flightless when the dove or swam to avoid our presence. Flightless flocks of harlequin ducks permitted close observation, either directly from the skiff or by herding large flocks past an observer concealed on shore.

RESULTS

Age and Sex Criteria

Spring

Our description of adult male (full nuptial) and female plumage patterns correspond to 'definitive alternate plumage' described by Palmer (1976). Plumage patterns for sub-adults males (FYM and SYM) best correspond to 'alternate I plumage' (Palmer 1976). Individual variation in size and intensity of markings existed in both sexes. Our descriptions use only definitive characteristics that were consistently observable in the field. Study skins or photographs were useful in revealing subtle characteristics not apparent in the field. Color contrasts and visibility of some markings changed with lighting conditions, angle observed, and posture of ducks.

We separated male harlequin ducks into one of three age classes: adult (AM); second-year (SYM); and first-year (FYM) (Table 1). We could not distinguish between age classes of females. We differentiated FYM from female harlequin ducks using head and body characteristics (Table 2, Figure 3). Females lacked neck and body stripes present on FYM, and showed little color contrast between head and body. Because of their relatively drab coloration, females were easily distinguishable from SYM and AM prior to molting.

Males were classified as FYM when the white neck collar and white tertial feathers, present on SYM and AM, were not visible (Table 3). We distinguished SYM from AM by differences in coloration of wing, head, and body markings (Table 3). We observed a gradual color change in males as the season progressed. The molting of body feathers, which reveals underlying coloration, and wearing away of gray margins on feathers of sub-adult males probably caused the color change (Palmer 1976). Further, because the timing and duration of the molt varies in both sexes (Palmer 1976), an array of plumage patterns appears as body feathers are molted but birds are still flight capable. Consequently, by mid-June certain white areas may became more apparent, such as scant traces of a neck collar in otherwise FYM and more boldness in white markings of SYM. As the molt approached some AM molted body feathers giving them a mottled appearance similar to that of SYM. Careful observation and use of multiple characters was necessary to avoid misclassification of males in late June.

Fall

We could not distinguish between age classes of harlequin ducks during the molt. Differences in plumage patterns between males and females, however, were easily discernible and corresponded with the descriptions of Palmer (1976). We relied on color contrast of the head and body to separate males from females. The darker, slate gray head of males contrasted with the brown body, whereas females exhibited little contrast between head and body coloration, and appeared a uniform brown. Less than ideal light conditions sometimes required repeated efforts and extra time to observe these subtle differences. The white cheek patch of females extends more posteriorly than in males, shortening the gap between the posterior edge of the cheek patch and the auricular patch (Figure 3). However, this must be viewed perpendicularly and is not as reliable as contrasting coloration or white tertial feathers. Males could be readily identified after the emergence of white tertial feathers.

Areas Surveyed and Survey Dates

We surveyed 35 unique locations in WPWS for harlequin ducks during 3 spring and 5 fall-survey periods (Table 4). Our survey locations were primarily situated in the central portion of western PWS (Fig. 2). Only Culross Island was surveyed during each survey period (Table 4). Twelve locations, however, were surveyed during each of the 3 spring-survey periods, while others were surveyed less frequently. Fifteen locations were surveyed in at least 3 of the 5 fall-survey periods (Table 4). During fall surveys, length of shoreline surveyed varied among survey periods, locations and, for some locations, varied among survey periods (Table

5). Variation also existed in our survey effort among spring-survey periods because emphasis was placed on developing methods for age and sex classification.

Seasonal Variation in Harlequin Numbers

Spring Population

For those locations surveyed repeatedly in the spring (n=12) (Table 4), the number of harlequin ducks declined steadily from late May through late June (Fig. 4). The proportion of males increased from 64%, 77%, to 87% of the population from the 1st through 3rd survey (Figures 5 and 6). Conversely, the proportion of females declined from 36%, 23%, to 16% (Fig. 5). The number of paired harlequin ducks also declined during this period (Fig. 6). Fifty-two percent, 30%, and 14% of the female component of the population were paired during the 1st, 2nd and 3rd spring survey, respectively (Fig. 6). However, only 29%, 9%, and 3% of the male population were paired (Fig. 6).

We only used the 3rd spring survey (June 19-23) to classify male harlequin ducks by age because ongoing development of methodology precluded our use of prior survey data. Consequently, we cannot report on temporal variation in the age structure of males. Fifty-three percent of the total population and 76% of the male population was classified as adults, whereas 3.9% and 10.8% of the male population was classified as SYM and FYM, respectively (Fig. 7).

Fall Population

The number of harlequin ducks observed in western PWS increased during our fall surveys (Fig. 4). Relative densities varied among and within our survey locations, but overall density increased steadily throughout the fall-survey period (Table 5). The number of males and females increased during this period, but relatively more females migrated into the survey area. The proportion of males declined from 81% to 54%, whereas the proportion of females increased from 19% to 46% (Fig. 5).

Molting Chronology

By late July, 94% of males and 48% of females were flightless (Fig. 8). The proportion of flightless males peaked at 99.5% during the 4-11 August survey period and declined to 7.6% on 9 September. On 30-31 August, the proportion of flightless females peaked at 82% then declined to 38% on 9 September (Fig. 8)..

Broods

The only brood observed was found in Hanning Bay on Montaque Island (Fig. 2). A female with two Class IIb (Gollop and Marshall 1954) ducklings was observed on 8 August near the mouth of Hanning Creek.

Temporal Variation

Relative numbers and densities of harlequin ducks varied among and within locations during the spring and fall surveys (Tables 4 and 6). Variability in numbers of harlequin ducks occurred over short periods of time (2 - 4 days) for a given location (Figure 9). Population trends were observable during the course of the season, however, when all locations were combined (Figure 4).

DISCUSSION

Sex and Age Criteria

Sex

Criteria separating adult male and female harlequin ducks in spring are well documented (Palmer 1976, Carney 1992). Adult males in full nuptial plumage are easily distinguished from females during field observations. Second-year males exhibit many of the same plumage characteristics of adults (Table 3), also making them easily distinguished from females. First-year males, however, are more similar in appearance to females than other male age classes. Familiarity with diagnostic plumage characteristics allowed us to accurately separate these classes under field conditions. We also found it obvious to distinguish males from females during the molt, especially when birds were flightless.

Age

Our age classification for male harlequin ducks assumes definitive plumage is acquired in the third year (Dement'ev and Gladkov 1967, Chadwick 1992, Goudie pers. comm.). The age at which harlequin ducks reach sexual maturity and attain adult plumage (definitive alternate plumage; Palmer 1976) is uncertain. Nor is it certain if the two events coincide. Our age categories should be considered a "working hypothesis" because no known age birds were used in its development. We could not separate females by age, nor believe it is possible without morphological examination.

The number and proportions of subadult birds in a population can be used to measure recruitment and detect changes in productivity. Criteria separating age and sex classes is only useful when methods are standardized. We are confident that reliable estimates of the age and sex composition of the harlequin duck population in western PWS can be determined using plumage characteristics and observation methods we have developed.

Population Structure, Distribution, and Abundance

During spring, the numbers of harlequin ducks utilizing PWS decline as breeding birds move to mountain streams and up river systems to nest. From July through September, harlequin numbers increase as birds return to coastal areas to molt (Isleib and Kessel 1973). At least in their first year, harlequin ducks remain along the sea coast (Dement'ev and Gladkov 1967). Inland studies on breeding areas in the Rocky Mountains of North America provide no evidence that subadult males (first- and second-year) migrate to the breeding grounds (Kuchel 1977, Wallen 1987, Cassirer and Groves 1992, Diamond and Finnegan 1993). Only Bengtson (1972) recorded immature males (1-2% of the males) on breeding rivers. It is likely that most subadults birds, males and females, remain along the coast until at least their third-year of life. Cloacal examination of 48 sub-adult females from inland breeding streams in Iceland revealed no immatures (Bengtson 1972), although Crowley and Patten (1995) captured unpaired, non-breeding females near coastal stream mouths in eastern PWS.

Spring

As spring progressed the number of paired harlequin duck decreased by approximately 90% (Figure 6). This decline occurred while the number of males in the population increased and the number of females decreased. Fleischner (1983) attributed a dramatic decrease in the number of pairs in late May to pairs departing for breeding areas. Because our first survey coincided with the timing of peak nest initiation in PWS (derived from data collected in 1991, 1992, 1993; Crowley and Patten 1995), we believe the decrease in pairs we observed probably began before our surveys started and continued to decrease through the course of our surveys (Figure 10). As the total number of females dropped simultaneously with the loss of pairs, this decrease in pairs likely represents a departure for breeding areas. Some females may have moved to molting sites outside our study area.

Male departures from nesting areas for coastal areas correspond with the onset of incubation (Bengtson 1972; Kuchel 1977; Dzinbal 1982; Cassirer and Groves 1992; Diamond and Finnegan 1993). Crowley (1995) reports males departing coastal streams after the second week of June, coinciding with the onset of incubation (Figure 10). Males generally outnumber females in duck populations because females are more susceptible to predation and stress due to the demands of incubation and brood rearing (Bellrose 1976). Few studies have looked at spring ratios in coastal areas. In this study, the proportion of males steadily increased from 64% to 87% from late-May to late-June. Male surpluses, from 54% to 66% are also reported from inland nesting areas (Bengtson 1966, Bengtson 1972, Kuchel 1977, Inglis et al. 1989, Cassirer and Groves 1992). A greater male surplus would be expected on coastal areas because of the presence of resident, non-breeding sub-adult and adult males which do not migrate inland.

There is little information comparing ratios of subadults to adults. For a March population, Chadwick (1992), reported that 5.2% of the pre-breeding population were sub-adults. This would be expected to increase in spring as adults migrate to breeding grounds. The only spring comparison is from Kodiak Island, Alaska. Subadult males comprised 8% of the total population and approximately 14% of the male population in mid-May (Zwiefelhofer 1994). This would be expected to decrease as spring progressed and adult males returned from breeding areas.

Fall

Densities increased throughout the fall as birds returned from breeding areas to molt. Non-breeding birds which remain in PWS molt first, followed by males immigrating from breeding areas. Females molt later than males as they remain on breeding areas longer than males regardless of breeding success. Most males are flightless in late July and early August.

Harlequin ducks exhibit fidelity to molt sites (Patten 1995). Molting birds are relatively stationary, therefore, molting populations may serve as the best measure of population trends. Comparisons of temporal changes in male:female ratios are useful to compare nesting chronology and are indicative of the number of breeding versus non-breeding birds in the population. Post-breeding females are the last birds to become flightless (Palmer 1976).

Brood Surveys

Pre-spill information on productivity of the 'resident' population of harlequin ducks in PWS is lacking. Prior to the spill no inclusive brood surveys had been conducted for PWS. "Isleib has seen scores of broods during July and August along the shorelines, especially in Prince William Sound" (Isleib and Kessel 1973). Sangster et al. (1978) reported a brood of nine on the coast of Naked Island. Oakley and Kuletz (1979) reported six brood aggregations along Naked Island totaling 72 young and one aggregate brood of 20 at Little Storey Island. They also observed 36 young in 2 groups around an offshore rock along the coast of Eleanor Island. Holbrook (pers. comm. in Patten 1994a) reported a brood on Otter Creek, Knight Island in 1982.

Patten (1995) and Patten et al. (1995) observed eleven broods at six locations from 1989-1992 and three broods at three locations in 1993 in oiled areas of western PWS. Kuletz (pers. comm. in Patten 1995) found no harlequin duck broods around Naked Island in post-spill surveys from 1989-1992.

We saw no indication of reproduction in the heavily oiled areas of western PWS. The only brood was located in Hanning Bay. Hanning Creek resembles no other creek in the survey area. It emanates from a much larger watershed and has a shallow gradient. This lack of reproduction is similar to what Patten et al.(1995) found from 1991-1993.

While we found only one brood in western PWS in 1994, Zwiefelhofer (1994) reported a low estimate of 48 broods along 974 km of coastline. Most of these were located in "offshore" islet and island habitat. Whether birds nest in these locales is unknown. Crowley and Patten (1995) suspected that harlequin ducks in PWS do not nest on offshore rocks, islets, or similar habitats.

Accurate brood counts, another measure of productivity, are difficult to obtain in Prince William Sound due to weather, remoteness, and brood behavior and habitat. There has been little to no indication of coastal nesting (coastal streams or small islands) in oiled areas of western Prince William Sound from 1991 through 1994 (Patten 1995, Patten et al. 1995), yet subadult birds are present in spring. Counts of subadults, another indication of recruitment, can supplement brood counts. Chadwick (1992) warns that results of subadult censuses be used cautiously as a measure of productivity, because of the clumped distribution of subadults. We did not observe a clumped distribution of subadults in our study, any more or less so than adults. We do not know the extent of movements or natal location of subadults, but there appears to be a great deal of variation for any given location. This implies that a great deal of movement may be occurring but the extent is unknown.

Unfortunately, there is little definitive pre-spill baseline data to adequately indicate the historical extent of coastal nesting and brood rearing in western PWS. Estimates of expected productivity in western PWS, based on observed nesting and brood rearing activity in eastern PWS, are tenuous because there has not been a comprehensive habitat evaluation that compares amount of suitable nesting and brood rearing habitat between the two regions. Island habitat and stream characteristics in western Prince William Sound may differ greatly from predominantly mainland or large island habitats in eastern Prince William Sound which have been used for comparative purposes by Patten (1995) and Patten et al. (1995). Streams in the oil spill area surveyed for breeding activity are of shorter length than those in the "control" area (Crowley and Patten 1995). Unfortunately no habitat assessment has been conducted in western Prince William Sound comparable to that conducted in eastern Prince William Sound by Crowley (1994). No stream flow data is available for most of the oiled portions of Prince William Sound. Crowley (1994) found stream flow to be the most important variable to predict nesting suitability of streams.

Low reproductive success of harlequin ducks in PWS since the spill should have resulted in changes in age and sex structure towards a greater proportion of adult males. Because we can classify males by age in spring, we can design repeat surveys that will document changes in abundance; distribution; number of breeding pairs; and age and sex structure of the population. The ratios and timing of these changes in population structure and abundance should be indicative of the current breeding behavior of the population. The ratio of subadult to adult males will serve as an index of recruitment, an indication of past breeding success. These parameters can be compared for populations of harlequin ducks inhabiting oiled and unoiled areas.

If reproduction is continually low or absent, populations will decline if no immigration occurs. Harlequin duck production and post-breeding abundance can be documented by conducting repeat surveys in the late summer and fall during the post-nuptial molt. Seasonal changes in sex ratios and abundance will indicate current breeding behavior and year to year changes in abundance will indicate population trends. Brood surveys will measure productivity. These can be compared for populations in oiled and unoiled areas to detect differences or similarities.

CONCLUSIONS

We developed field criteria, based on plumage characteristics, to classify male harlequin ducks into 3 age classes during spring. Monitoring annual changes in age structure will provide indices of recruitment (proportion of subadults) and adult survival (number of adults along standardized surveys) for the harlequin duck population in western PWS. We also developed criteria to classify harlequin ducks by sex during breeding and molting periods. Seasonal changes in sex ratio indicated chronological events such as departure for breeding grounds, nest initiation, disbanding of paired ducks and arrival at molting areas. Annual variation in sex ratio may reflect breeding potential of the population.

We designed a sampling technique using standardized survey-segments over broad regions to be surveyed repeatedly throughout the breeding season. Repeated surveys will allow for temporal (both annual and seasonal) and spatial comparisons of sex, age, and abundance of harlequin ducks comprising populations in oiled and non-oiled areas of PWS.

Annual monitoring of population structure and reproductive success of harlequin ducks will allow us to assess trends and suggest factors limiting recovery. This will provide a more reliable basis for restoration planning and be consistent with an adaptive management approach that allows more efficient allocation of efforts and enrichment of knowledge over time (e.g. for a long-term monitoring program). Results of this work will have a direct bearing on assessing the status and outlook for this resource and guide agency programs and policies related to public uses, especially subsistence and recreational hunting, and wildlife viewing.

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Table 1. Age classification of harlequin ducks observed during shoreline surveys in Prince William Sound, Alaska prior to July 1.

Age class	Approximate age	Age in calendar years
Adult	>2 years	Third or older
Subadult[a]	< 2 years	Third or second
Second year	> 1 and <2 years	Third
First year	< 1 year	Second

[a]Collective term for first and second year (immature) birds

Table 2. Characteristics used in distinguishing first-year (1 year old) male from female harlequin ducks in Prince William Sound, Alaska prior to July 1.

Morphology	Sex and age	Criteria
Wing	FYM:	No difference
	Female:	No difference
Head and Body	FYM:	White neck stripe; white cheek patch extends dorsally anterior to eye extending to crown, greater contrast with head; white breast stripe indistinct; slate gray head and neck contrasts with brown body.
	Female:	Neck stripe absent; breast stripe absent; white cheek patch less vibrant, broken anterior to eye with brown mottling, does not extend to crown; little contrast between brown head and body.

Table 3. Characteristics used in differentiating 3 age classes of male harlequin ducks in Prince William Sound, Alaska prior to July 1.

Morphology	Age	Criteria
Second-year males (SYM) from first-year males (FYM)		
Wing	SYM	Distal three tertials white on outer webs.
	FYM	Wing all brown.
Head and Body	SYM	Neck collar incomplete/indistinct.
	FYM	Neck collar absent.
Second-year males from adult males (AM)		
Wing	SYM	Distal three tertials white on outer webs; No white spots on wing coverts: Wing predominantly brown.
	AM	Distal three tertials white on outer webs; Wing coverts w. white spots; Wing with blue iridescence.
Head and Body	SYM	Neck collar incomplete/indistinct. Breast mottled; Belly light; Bold vivid coloration of adult males lacking; Muted crown markings; Face steel gray; White auricular patch, neck stripe, and lores do not contrast as greatly with head.
	AM	Scapulars white; Breast and belly uniformly dark; Neck collar distinct and complete except possibly at throat, vivid white and boldly margined with black. Breast stripe broad, vivid white, boldly margined with black; Head deep blue.

Table 4. Numbers of harlequin ducks counted during shoreline surveys in western Prince William Sound, Alaska in 1994

	Spring Survey Dates			Fall Survey Dates				
Survey Location	May 25-30	June 3-9	June 19-23	July 23-30	Aug. 4-11	Aug. 18-23	Aug. 30-31	Sept. 9
Aguliak Island	dns[a]	0	0	dns	8	dns	dns	dns
Applegate Island	20	54	29	dns	24	34	28	5
Bainbridge Bay	dns	2	dns	dns	dns	dns	dns	dns
Bay of Isles	91	0	8	41	71	31	dns	dns
Brizgaloff Creek	dns	dns	63	43	11	38	dns	dns
Channel Island	dns	dns	dns	105	113	102	dns	dns
Clam Island	dns	3	dns	dns	1	dns	dns	dns
Crafton Island	40	55	19	36	dns	53	92	dns
Culross Island	24	21	0	7	57	61	80	111
Delenia Island	18	30	0	18	12	6	dns	dns
Drier Bay	0	dns	dns	dns	8	dns	dns	dns
Eshamy Bay	dns	dns	12	8	17	dns	dns	dns
Ewan Bay	dns	dns	dns	0	0	0	dns	dns
EW900	dns	dns	dns	0	dns	17	dns	dns
Falls Bay	dns	dns	dns	17	dns	45	65	73
Foul Bay	40	9	9	40	dns	67	90	102
Foul Pass	dns	dns	dns	0	dns	0	dns	dns
Green Island	dns	dns	dns	202	263	393	dns	dns
Hanning Bay	dns	dns	dns	dns	49	dns	dns	dns
Herring Bay	14	1	1	12	dns	4	dns	dns
Jackpot Bay	dns	0	dns	6	0	2	dns	dns
Johnson Bay	dns	3	5	dns	2	dns	dns	dns
Junction Island	44	34	33	6	21	17	dns	dns
Logjam Bay	28	42	44	36	31	51	dns	dns
Main Bay	0	0	38	7	dns	27	19	dns
Masked Bay	1	10	0	4	9	24	dns	dns
Mummy Island	dns	14	22	dns	28	29	dns	dns
Naked Island	dns	dns	dns	12	18	26	dns	dns
New Years Island	0	dns	dns	dns	0	dns	dns	dns
Pt. Nellie Juan	dns	dns	dns	16	dns	15	9	dns
Squire Island	dns	7	1	dns	19	dns	dns	dns
Squirrel Island	dns	0	7	dns	18	dns	dns	dns
Storey Island	dns	dns	dns	dns	17	38	dns	dns
Totemoff Creek	2	20	0	4	0	22	dns	dns
West Knight Island	dns	dns	dns	dns	24	dns	dns	dns
Total	322	305	291	620	821	1102	383	291

[a] dns = did not survey

Table 5. Lengths (km) and dates of shoreline segments surveyed for harlequin ducks in western Prince William Sound, Alaska in late summer and fall, 1994.

General Location	23-30 July	4-11 Aug.	18-23 Aug.	30-31 Aug.	9 Sept.
Aguliak Island	dns[a]	1.9	dns	dns	dns
Applegate Island	dns	5.9	5.9	5.9	5.9
Bay of Isles	32.9	33.9	33.9	dns	dns
Brizgaloff Creek	8.9	8.9	8.9	dns	dns
Channel Island	1.6	1.6	1.6	dns	dns
Clam Island	dns	1.6	dns	dns	dns
Crafton Island	6.8	dns	6.8	6.8	dns
Culross Island	3.6	49.5	49.5	49.5	22.3
Delenia Island	0.1	0.1	1.1	dns	dns
Drier Bay	dns	14.8	dns	dns	dns
Eshamy Bay	43.8	45.4	dns	dns	dns
Ewan Bay	11.5	9.4	9.4	dns	dns
EW900	4.4	dns	4.4	dns	dns
Falls Bay	7.2	dns	10.5	7.0	6.3
Foul Bay	2.1	dns	3.7	3.2	5.4
Foul Pass	7.7	dns	6.8	dns	dns
Green Island	51.5	51.5	51.5	dns	dns
Hanning Bay	dns	2.8	dns	dns	dns
Herring Bay	38.3	dns	7.5	dns	dns
Jackpot Bay	26.1	27.6	26.1	dns	dns
Johnson Bay	dns	17.8	dns	dns	dns
Junction Island	1.1	3.0	3.0	dns	dns
Logjam Bay	5.6	5.6	5.6	dns	dns
Main Bay	8.9	dns	8.9	7.1	dns
Masked Bay	4.0	6.0	2.3	dns	dns
Mummy Island	dns	6.5	8.9	dns	dns
Naked Island	73.2	73.2	63.2	dns	dns
New Years Island	dns	2.1	dns	dns	dns
Pt. Nellie Juan	2.2	dns	2.2	2.2	dns
Squire Island	dns	17.5	dns	dns	dns
Squirrel Island	dns	4.5	dns	dns	dns
Storey Island	dns	2.8	2.8	dns	dns
Totemoff Creek	5.4	5.4	5.4	dns	dns
West Knight Island	dns	32.1	dns	dns	dns
Total	346.9	431.4	329.9	81.7	39.9

[a] dns = did not survey

Table 6. Relative density (ducks/km shoreline) of harlequin ducks in western Prince William Sound, Alaska in late summer and fall, 1994.

General Location	23-30 July	4-11 Aug.	18-23 Aug.	30-31 Aug.	9 Sept.
Aguliak Island	dns[a]	4.2	dns	dns	dns
Applegate Island	dns	4.1	5.8	4.7	0.8
Bay of Isles	1.2	2.1	0.9	dns	dns
Brizgaloff Creek	4.8	1.2	4.3	dns	dns
Channel Island	65.6	70.6	63.8	dns	dns
Clam Island	dns	0.6	dns	dns	dns
Crafton Island	4.5	dns	7.8	13.5	dns
Culross Island	1.9	1.2	1.2	1.6	5.0
Delenia Island	180.0	120.0	5.5	dns	dns
Drier Bay	dns	0.5	dns	dns	dns
Eshamy Bay	0.2	0.4	dns	dns	dns
Ewan Bay	0.0	0.0	0.0	dns	dns
EW900	0.0	dns	3.9	dns	dns
Falls Bay	2.4	dns	4.3	9.3	11.6
Foul Bay	19.0	dns	18.1	28.1	18.9
Foul Pass	0.0	dns	0.0	dns	dns
Green Island	3.9	5.1	7.6	dns	dns
Hanning Bay	dns	17.5	dns	dns	dns
Herring Bay	0.3	dns	0.5	dns	dns
Jackpot Bay	0.2	0.0	0.1	dns	dns
Johnson Bay	dns	0.1	dns	dns	dns
Junction Island	5.5	7.0	5.7	dns	dns
Logjam Bay	6.4	5.5	9.1	dns	dns
Main Bay	0.8	dns	3.0	2.7	dns
Masked Bay	1.0	1.5	10.4	dns	dns
Mummy Island	dns	4.3	3.3	dns	dns
Naked Island	0.2	0.2	0.4	dns	dns
New Years Island	dns	0.0	dns	dns	dns
Pt. Nellie Juan	7.3	dns	6.8	4.1	dns
Squire Island	dns	1.1	dns	dns	dns
Squirrel Island	dns	4.0	dns	dns	dns
Storey Island	dns	6.1	13.6	dns	dns
Totemoff Creek	0.7	0.0	4.1	dns	dns
West Knight Island	dns	0.7	dns	dns	dns
Total	1.8	1.9	3.3	4.7	7.3

[a] dns = did not survey

Figure 1. Location of study area for harlequin duck surveys in Prince William Sound, Alaska.

Figure 2. Locations of transects established for harlequin duck surveys in western Prince William Sound, Alaska during 1994.

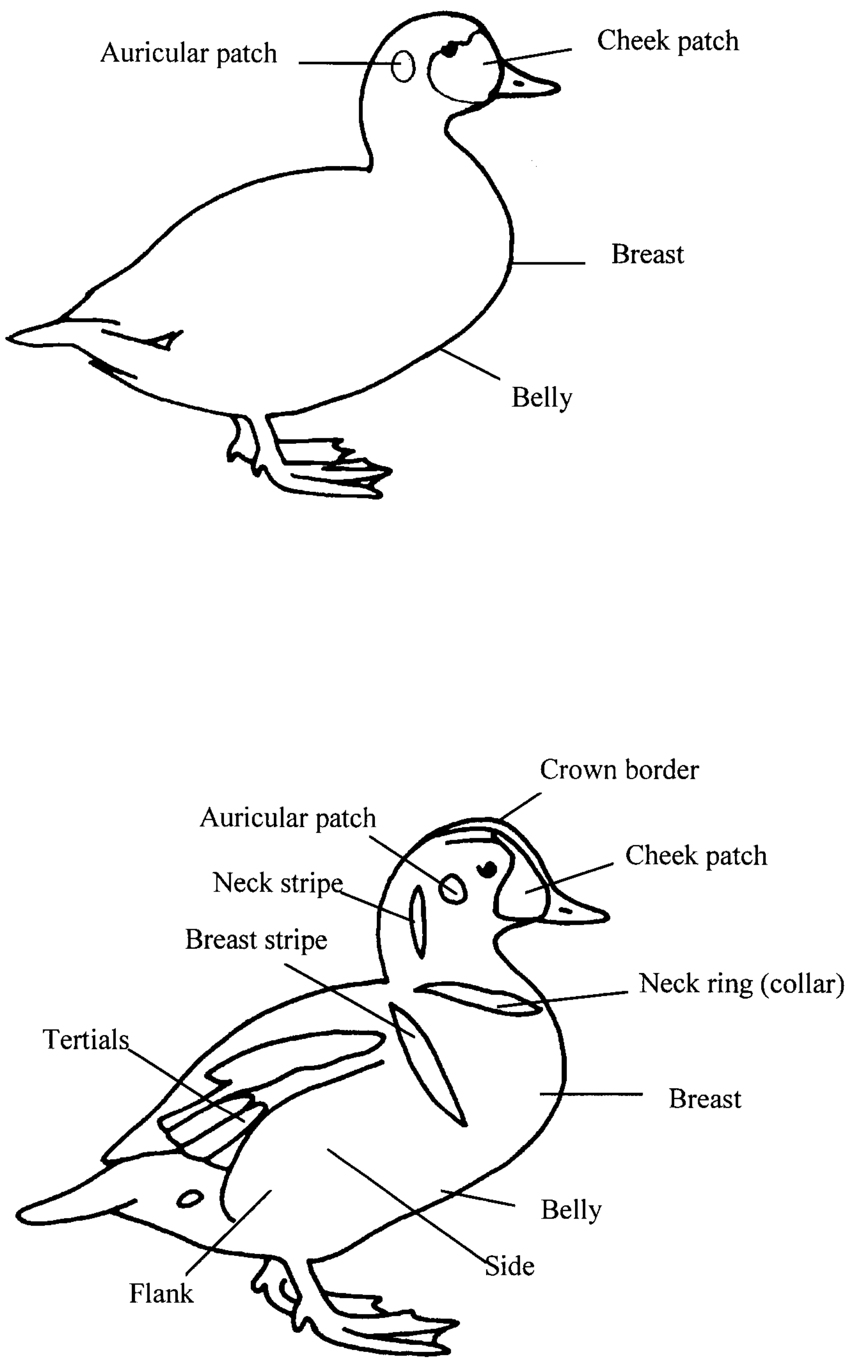

Figure 3. Sketch of female (top) and male (bottom) harlequin ducks illustrating characteristics used in distinguishing sex and age categories.

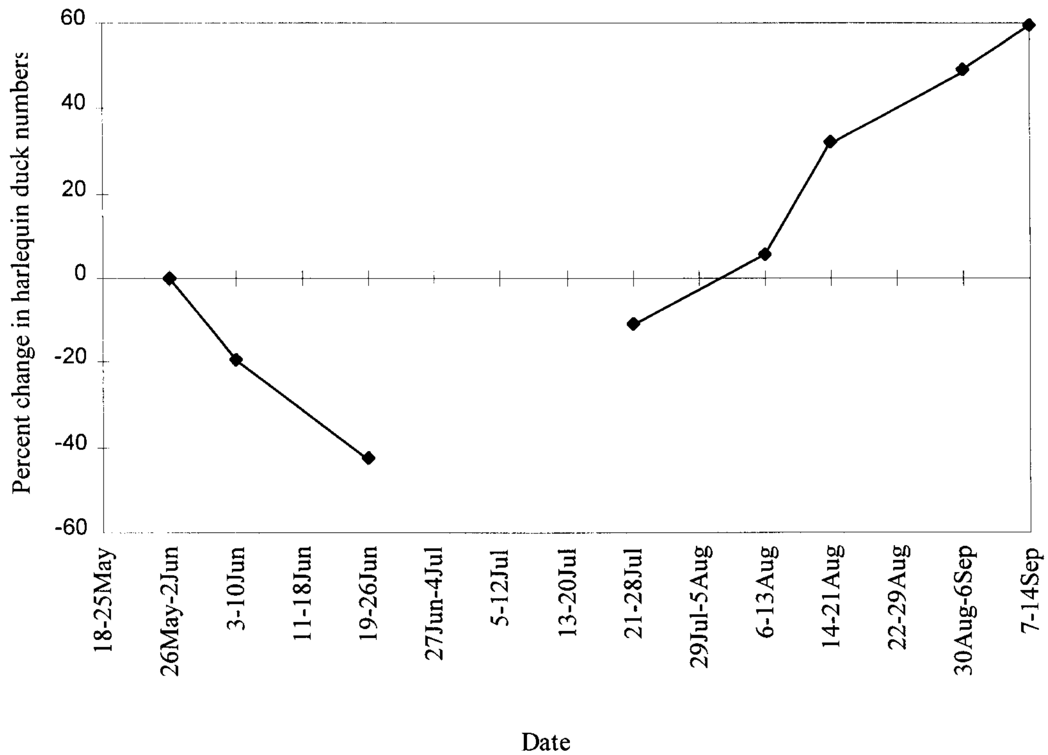

Figure 4. Estimated change in numbers of harlequin ducks observed in western Prince William Sound, Alaska along survey segments (range 4 - 16) visited on 2 or more consecutive surveys during 1994.

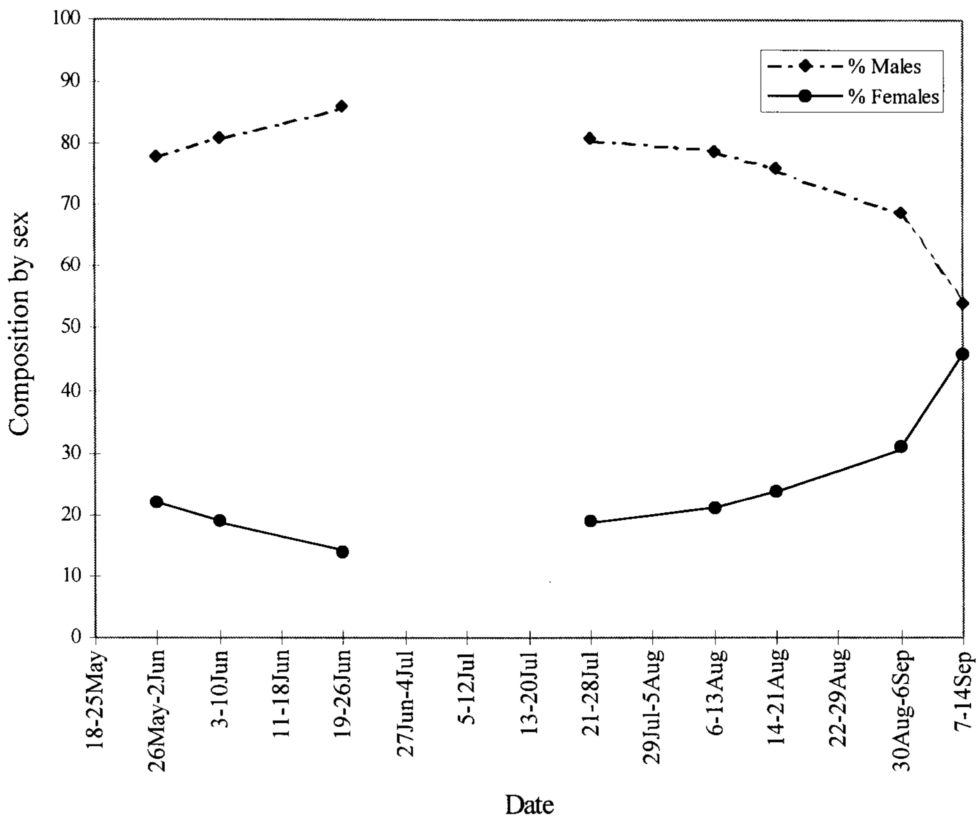

Figure 5. Proportion of harlequin ducks identified to each sex during 8 survey periods in western Prince William Sound, Alaska in 1994.

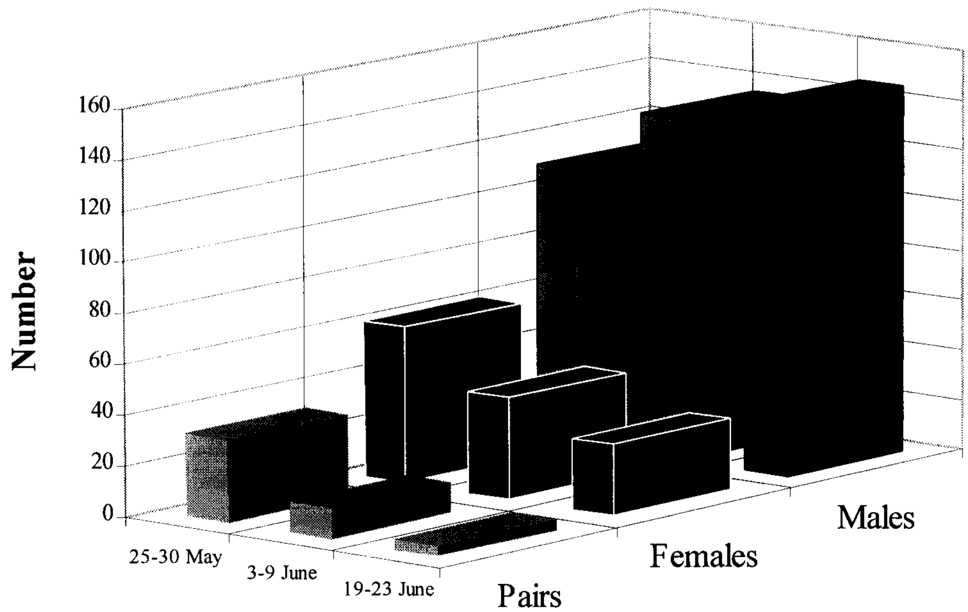

Figure 6. Number of males, females and paired harlequin ducks observed during spring surveys in western Prince William Sound, Alaska in 1994.

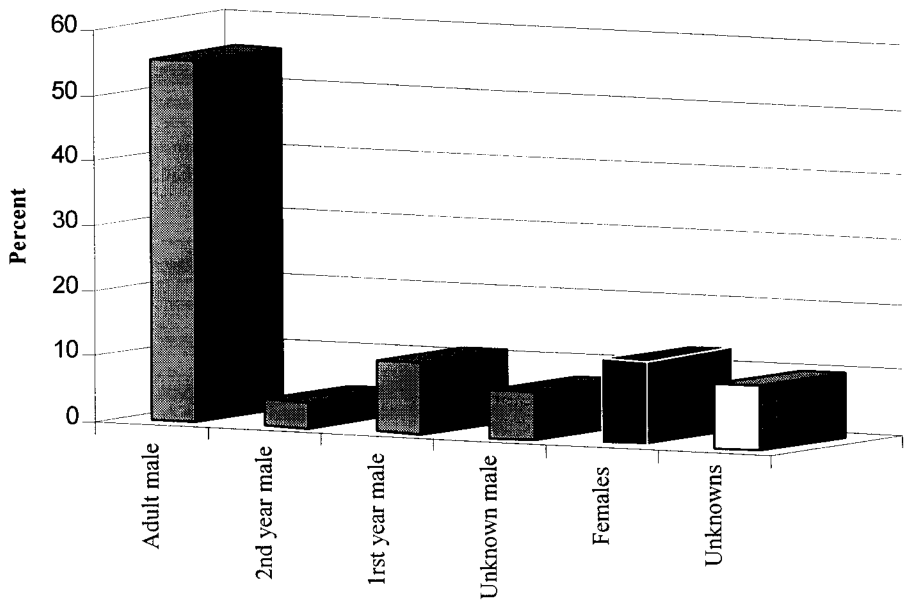

Figure 7. Age (no. years after hatching) and sex of harlequin ducks (n = 291) observed during 18 - 23 June, 1994, in western Prince William Sound, Alaska.

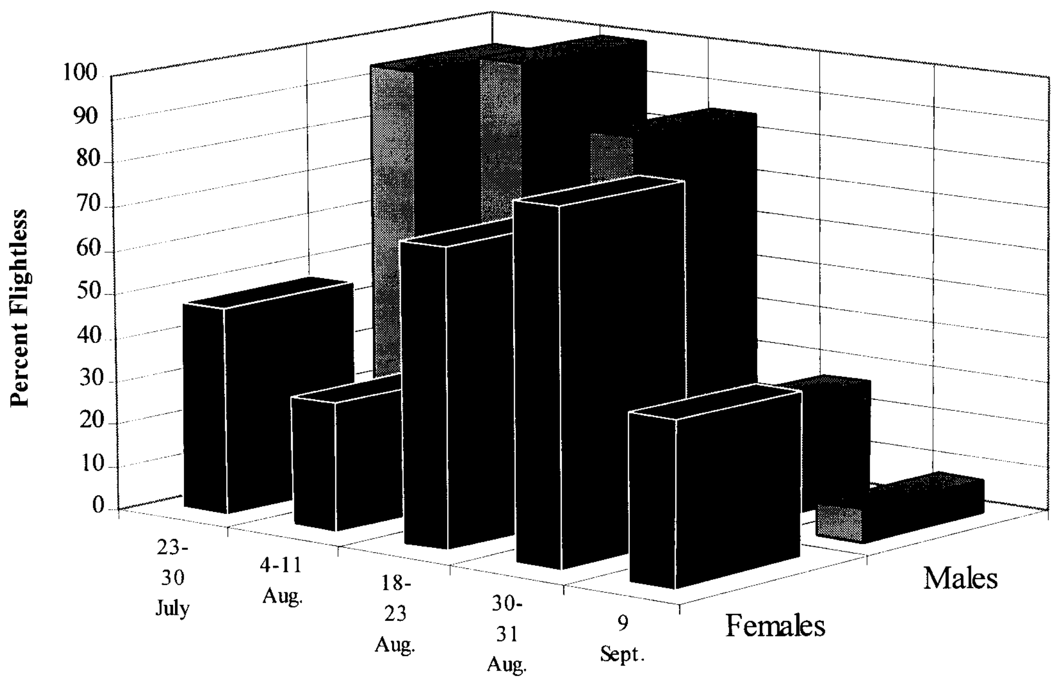

Figure 8. Proportion of flightless harlequin ducks observed during 5 consecutive shoreline surveys in western Prince William Sound, Alaska in 1994.

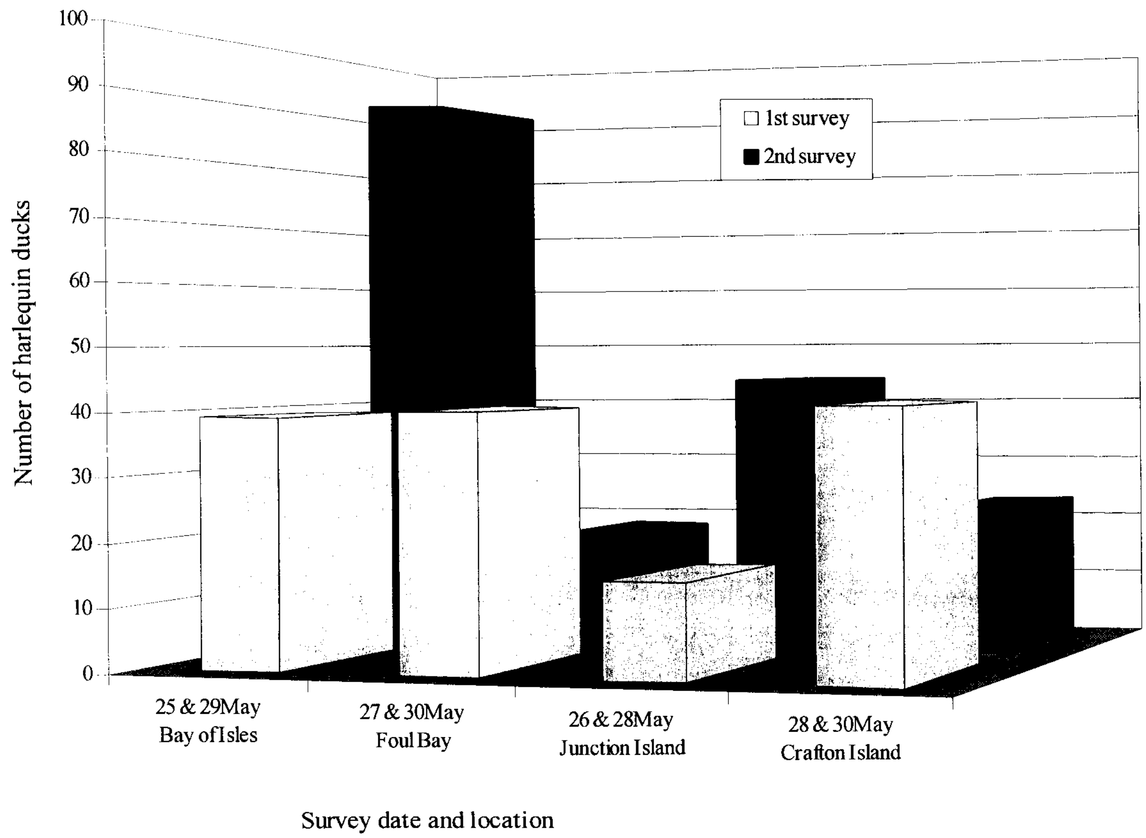

Figure 9. Temporal variation in numbers of harlequin ducks along 4 shoreline segments surveyed twice within 2 - 4 days in western Prince William Sound, Alaska in 1994.

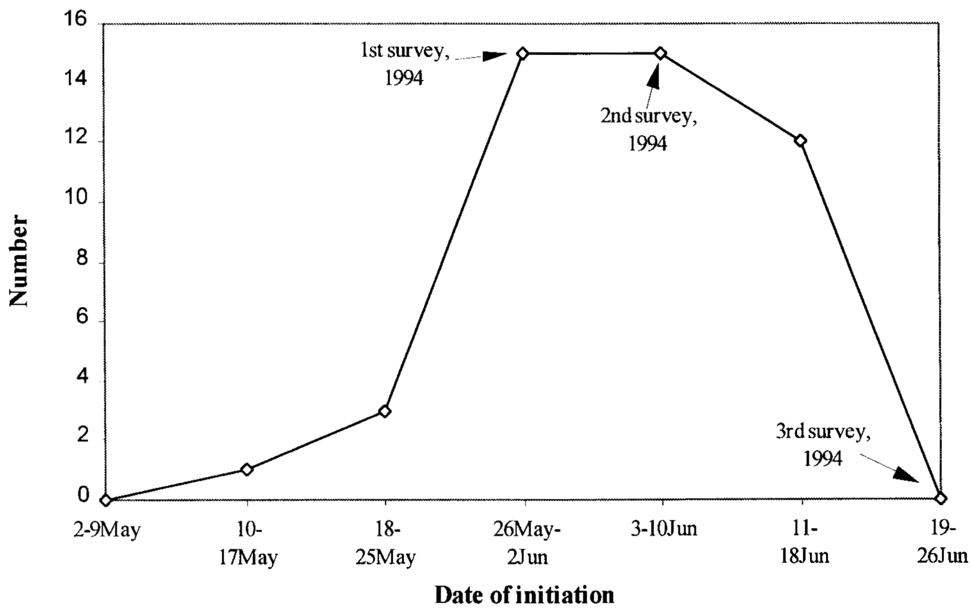

Figure 10. Predicted nest initiation by female harlequin ducks breeding in Prince William Sound, Alaska, 1991 - 1993, combined (Crowley and Patten 1995).