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SIMULATION OF FISH MOVEMENTS IN A LARGE HYDRO-ELECTRIC RESERVOIR: LG-2[1]

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ABSTRACT: Reservoir flooding creates a completely new habitat for fish to utilize. How they utilize this habitat will reflect the impact of the reservoir creation on the fish.

To examine the utilization of new habitat by fish, a two-dimensions model has been made of fish movements in the LG-2 reservoir. The model can take into account the effects of several factors on fish movements. While many researchers have studied swimming speeds in laboratories, such results are not applicable for obtaining displacement speeds in a natural system. Therefore, Monte-Carlo simulations based on fish-tracking studies have been used to estimate net displacements per unit time for individual fish. This information has then been used to give a time frame to the full-reservoir model.

The first use of the model has been to examine the dispersion of fish into the reservoir in the first year. Examinations have been done for the major species found in the area. Results are compared to catch-per-unit-effort data collected the year after flooding.

The model gives relative densities of fish at grid points in the reservoir over time. The results of the model have implications as to the interpretation of fish data collected after impoundment.

RESUME: L'inondation résultant d'un réservoir crée un habitat complètement nouveau que la faune ichtyologique va utiliser. La façon dont celle-ci va utiliser cet habitat sera une mesure en quelque sorte de l'impact de la création de ce réservoir sur les poissons.

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Afin d'étudier l'utilisation d'un tel habitat par cette faune, un modèle bidimensionnel a été posé pour le mouvement des poissons dans le réservoir LG-2 du réseau hydro-électrique de la Baie de James. Le modèle peut tenir compte de divers facteurs pouvant influencer le mouvement du poisson. Bien que la vitesse de nâge de certains poissons ait été mesurée sous des conditions de laboratoire par plusieurs chercheurs, ces résultats ne peuvent être utilisés afin d'obtenir la vitesse nette du déplacement dans un environnement naturel. En conséquence, des simulations de type Monte Carlo, basées sur des études de déplacement des poissons utilisant des traceurs, ont été réalisées pour estimer le déplacement net d'un poisson par unité de temps. Cette information fut alors utilisée afin de situer l'échelle de temps pour le modèle du réservoir entier.

La première utilisation du modèle fut faite pour l'examen de la dispersion du poisson dans le réservoir, la première année de sa création. Les principales espèces présentes furent considérées. Les résultats sont comparés avec les données pour l'effort de capture obtenues l'année suivant l'inondation.

Le modèle calcule la densité relative des poissons en fonction du temps aux points de coordonnées d'une grille superposée sur le réservoir. L'importance du modèle à titre d'outil interprétateur des données recueillies pour les poissons après la création du réservoir est discutée.

INTRODUCTION

With the creation of reservoirs, habitats are greatly changed for the fish populations present in water bodies prior to innundation. New habitat is made available from the flooded areas. Old habitat is also modified as it becomes deeper. Whether or not a particular species will benefit or suffer from these changes is dependent upon the prefered habitat of that species.

Food availability is also changed during a period of stabilization. The plankton can undergo a change in species distribution, and densities can also be affected by a dilution process. The benthos also undergo changes in species distributions and densities, and anoxia can eradicate many species from certain parts of the reservoir.

The operation of the reservoir after flooding can affect the breeding success of certain species. Water level fluctuations can greatly affect the extremities of a reservoir, and inappropriate timing of these fluctuations can destroy breeding areas.

Thus, the effects of reservoir creation can be seen to act on fish populations in 2 ways. The spatial distribution of the fish can change, and the size and dynamics of the populations can change. In most instances, these two effects will be completely confounded in a sampling program. A reduction in catch-per-unit-effort data could reflect increased mortality, decreased fecundity, dilution of the population, or displacement to more suitable habitat. To sort these effects out with a sampling program would be prohibitively expensive.

This problem is a prime example of how simulation modeling can be a complementary tool for biological monitoring programs. It is relatively easy to use a mathematical model to express how simple dilution of populations can change catch-per-unit-effort data at specific points in a reservoir. If sampling results differ greatly from projected results with such a model, the importance of factors other than simple dilution is indicated.

In this paper, such a model is presented. It examines changes in catch-per-unit-effort data collected in parts of the LG-2 reservoir in the James Bay region of Quebec, Canada before and after impoundment. Three species of fish are examined: the white sucker (Catostomus commersoni), the longnose sucker (Catostomus catostomus), and the walleye (Stizstedion vitreum). Aside from simple dilution, two scenarios for habitat selection are examined for each species: depth preferences and shore proximity (edge effect). The model predictions are compared to results obtained in 1979, the year after impoundment.

Model Rationale

For the species examined here, displacements of individuals are not that great in a natural water body. For example, the walleye seldom wanders more than 8 km over a whole season (Scott and Crossman, 1973). The meanderings of this type of individual can be well represented by a "random walk" model. An example of a random walk simulation of the movements of a white sucker are shown in Figure 1, based on data from Kelso (1976). This type of simulation can give information on typical random displacements and ranges, among other things.

Random displacements may be expected in a homogeneous habitat but this is rarely found in a natural system. Instead, there

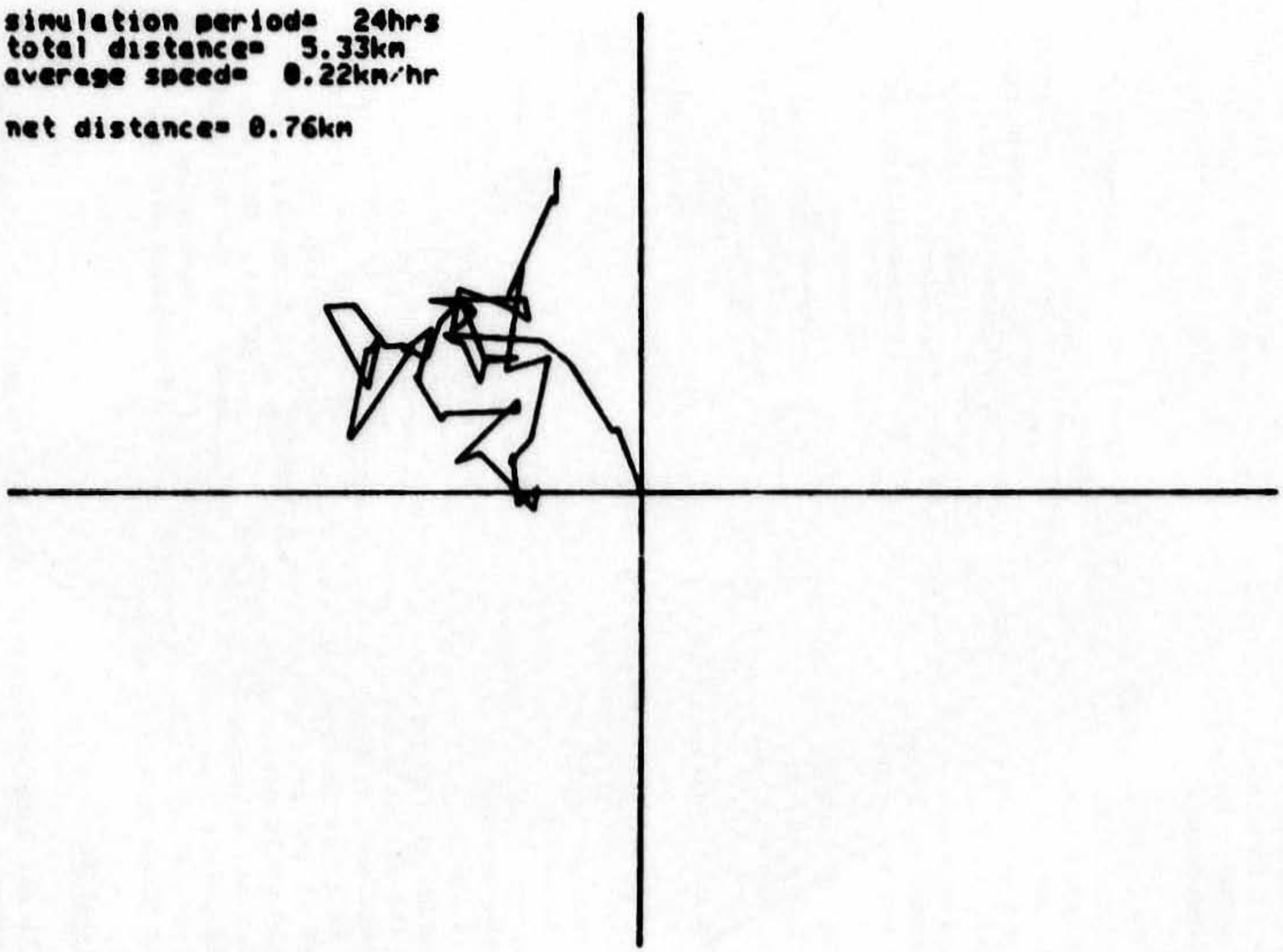

Figure 1. Random-walk simulation of the movement of a white sucker (*Catostomus commersoni*) over a 24-hour period.

are variations in temperature, oxygen, food, depth, etc. Fish can be expected to change their pattern of movements to stay in areas of favourable conditions, or at least to avoid unfavourable areas. Laboratory studies have indicated such preferences for temperature.

De Angelis (1978) constructed a model of the movements of individual fish to examine how different factors might alter the distribution of fish in 2 dimensions. For practical purposes he discretized the reservoir into a grid and examined movements from one grid point to another. One problem with this model, however, is that the horizontal and vertical distances between grid points are in km and m respectively, thus distorting the time scale of the model. In fact, no relation to real time is given for the model.

For our model, it was decided that some approximate time scale was necessary. All initial work was done for the white sucker, and the model was structured accordingly.

The LG-2 reservoir was divided into a horizontal grid, with distances between grid points being 2.5 km. Each grid point was considered to represent the surrounding area of 6.25 km^2, and was classified by depth and closeness to shore. These classifications include implicitly temperature and food availability factors. According to our simulations using the random walk model, the average random displacement was in the order of 1 km/day. Under the assumption of a uniform distribution of fish within the 6.25 km^2 area, the percentage of fish that would reach a surrounding grid point area is a function of the average speed versus the distance between grids. In our case, the percentage that would move from one grid point area to another was calculated to be approximately 50%. Thus for each time step, 50% of the fish at one grid point would remain at that point while the other 50% would displace to surrounding grid points. This displacement was affected by a preference function at the surrounding grid points based either on density alone at each point (hereafter called simple dispersion) or this combined with the depth or shore proximity of each point.

Initialization

Gill net data obtained from Boucher (1981) were transformed into catch-per-unit-effort for six sampling stations in the LG-2 reservoir (Figure 2). The variable considered was in fact kg per hour per 440 m^2 of gill net. Values were averaged over as many as 10 samples within each summer for each station.

These stations were originally chosen by the SEBJ as being representative of specific regions of the reservoir. We thus made the assumption that the catch-per-unit-effort would be the same in all water bodies in a given region prior to innundation. Therefore, within each of the six regions of the reservoir, the grid points corresponding to water bodies existing before flooding were initialized with the catch-per-unit-effort results from the station within that region for 1978.

Execution

Although the La Grande river was impounded in late summer of 1978, the major part of the innundation came during the spring melt. Thus we assumed that 90 days of displacement could take place before mid-summer of 1979. The model was run for 90 days (ie. 90 time-steps) and the results were compared to the average catch-per-unit-effort data for the same stations in 1979.

The assumptions used for white suckers were extended to longnose suckers and walleye, which is reasonable since the three species do not make far-ranging movements. A difference to note among the species is that longnose suckers prefer deep water while the other two species prefer shallow water (Scott and Crossman, 1973).

Results

The initial starting conditions are shown in Figure 3 for white suckers. Note that the reservoir is being viewed from the north-west. As an example of the distribution of catch-per-unit-effort at the end of a run, the results considering dilution and depth are shown in Figure 4. While more spread out than the initial conditions, it can be seen that the fish are tending to be around the periphery of the reservoir.

The results over time at the sampling station grid points for the three different scenarios are shown in Figure 5 for white suckers. At G2-400, no white suckers were found in 1978. The increase over time estimated by the model is due to the influx of fish from other parts of the reservoir. Note that the predictions based on depth as a factor modifying dispersion differ greatly from predictions based only on dispersion or dispersion modified by shore proximity. This is because G2-400 is a very deep station, but is relatively close to shore. The

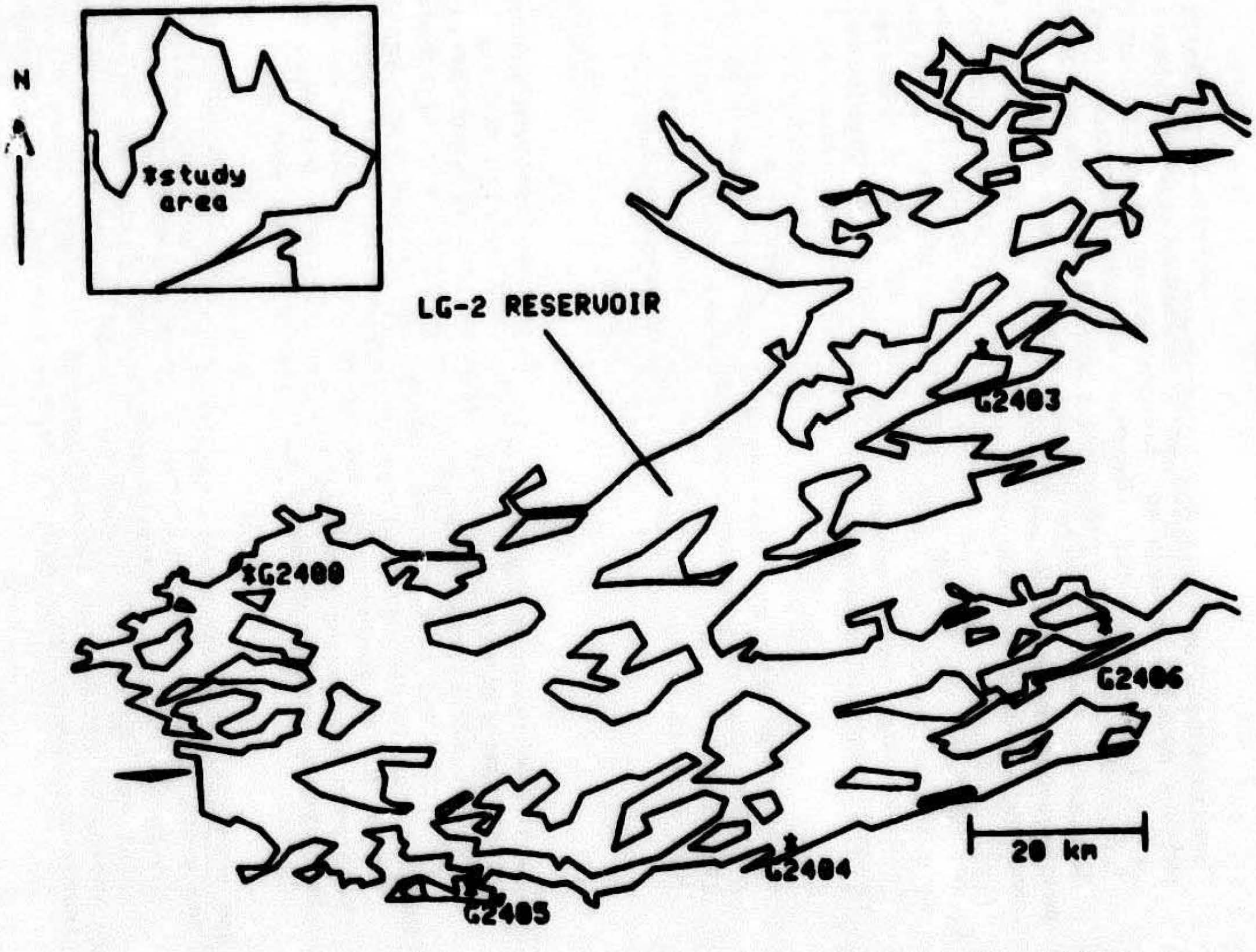

Figure 2. Map shwoing study area and locations of sampling stations.

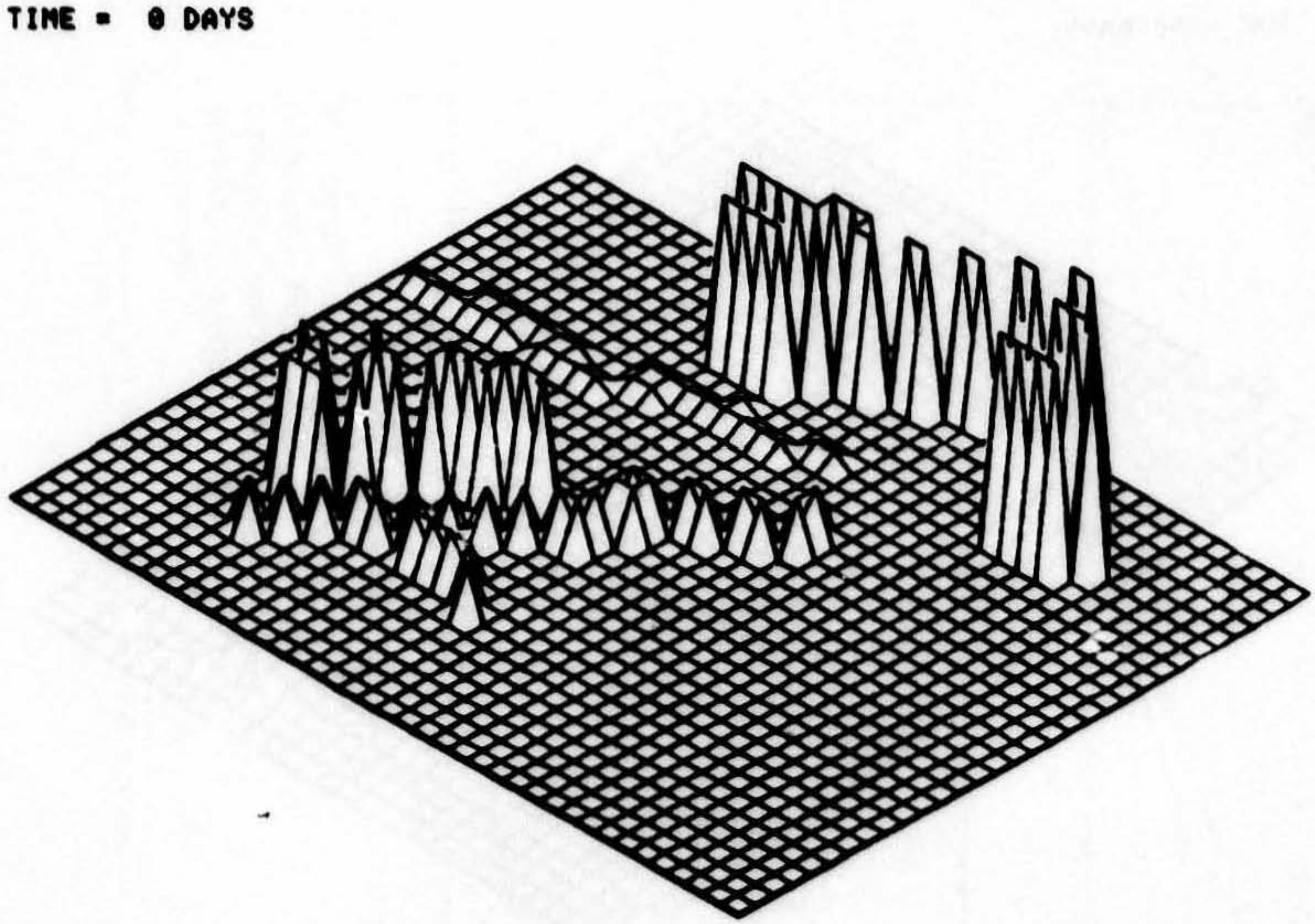

Figure 3. Initial conditions for a simulation of white suckers.

TIME = 90 DAYS

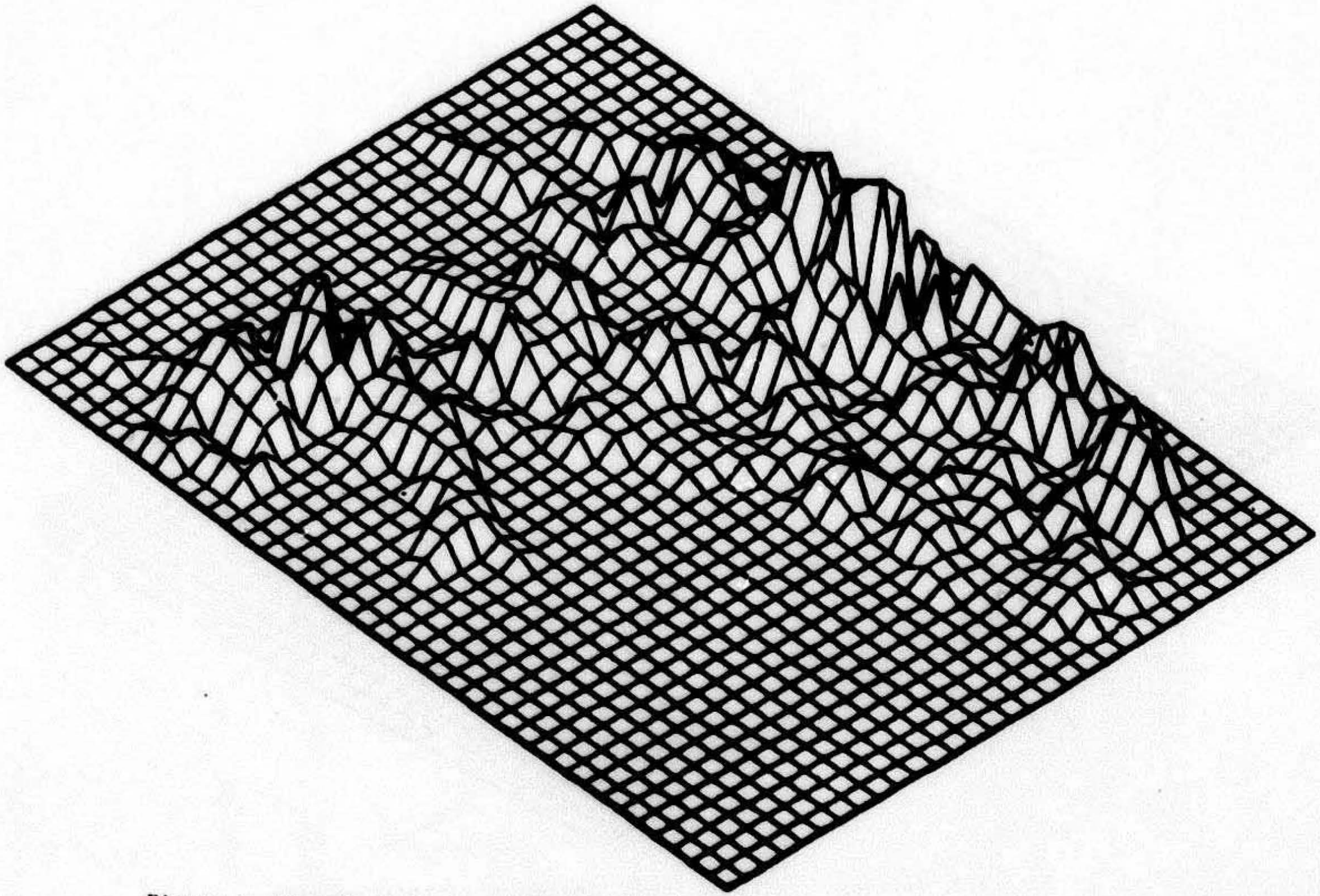

Figure 4. Distribution of white suckers after a 90-day simulation using depth
a factor modifying

observed catch-per-unit-effort in 1979 lies between the scenarios. At the other stations, the differences between the different scenarios are not as great, and except for G2-405, the 1979 results are fairly close to the estimated values. At G2-405 however, the model predicts a decrease while in fact there was a slight increase, although given random error the increase was not significant.

The same set of results are shown in Figures 6 and 7 for the other two species. For the longnose sucker the predicted changes at station G2-400 are not as different as for white suckers, since the longnose sucker prefers deep water. At four of the six stations, the model underestimates the densities, especially at G2-406. For the walleye, results are somewhat similar to those for the white sucker. There are important differences between model predictions and observations at two of the six stations.

Discussion

In general, model predictions do not depart greatly from observations, except in one case, that of the longnose sucker at G2-406. However, the magnitudes involved in this case are relatively small, and the relative error is large while the absolute error is not.

We do not pretend that the model is yet complete. Some of the assumptions made are in fact somewhat crude. For example, the assumption that the whole reservoir was flooded on day 0 is unrealistic. In fact, stations G2-405 and G2-406 were not really affected by flooding until the summer of 1979 (Schetagne, 1981). The representations of depth and shore proximity were also somewhat crude. That the model results are as close to the observed results as they are indicate that in spite of the lack of refinement the model is giving a reasonably good representation of the dispersion processes occuring. The model also gives at least an indication of how much of the changes between the two years could be due to displacement processes only in contrast to biological processes.

CONCLUSIONS

Given that the work presented here is still ongoing and the results only preliminary, the model is giving surprisingly good estimates of the changes in catch-per-unit-effort from one year to the next. Further refinements will of course be done to the

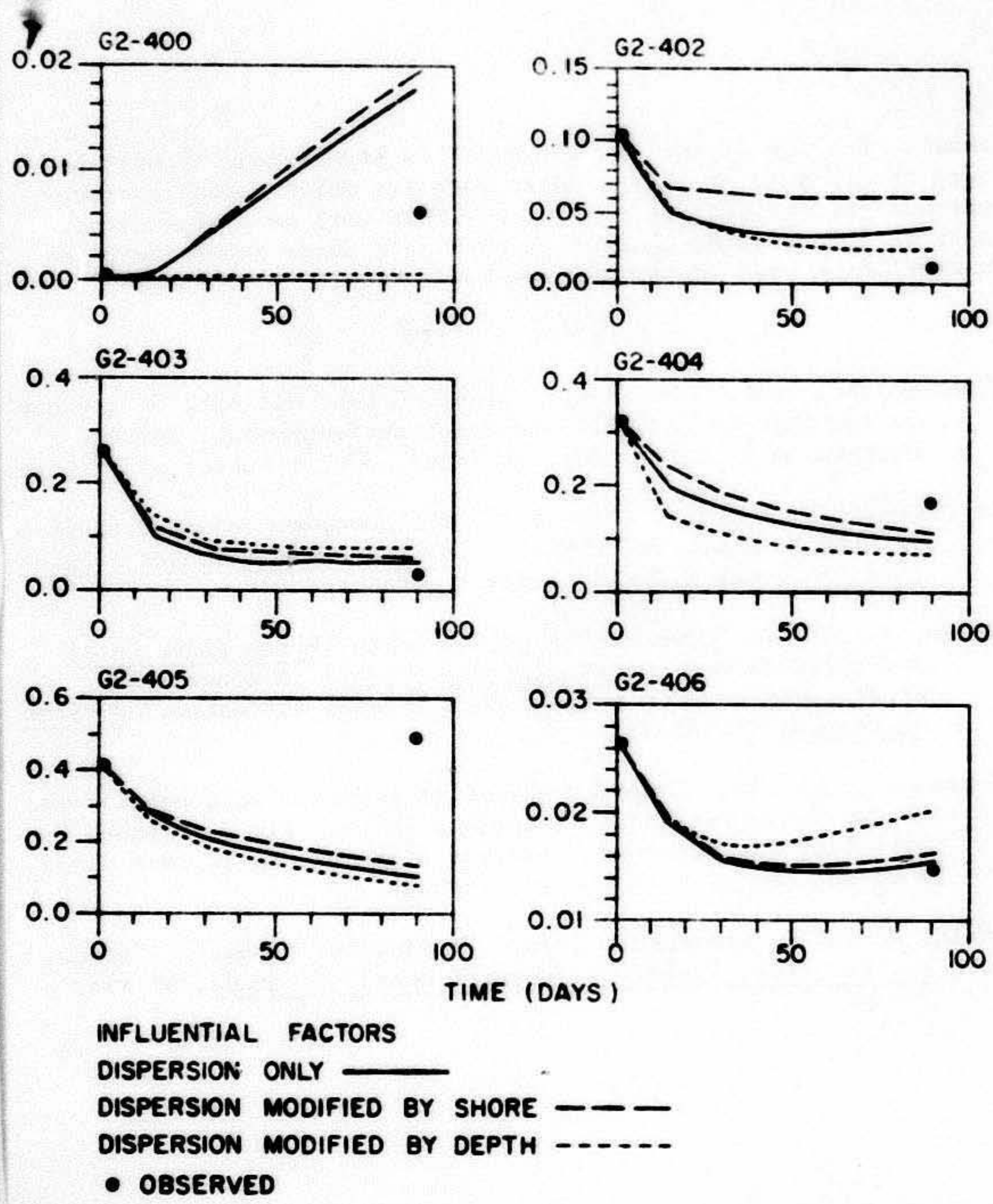

Figure 5. Calculated catch-per-unit-effort of white suckers at the sampling stations using the three different scenarios.

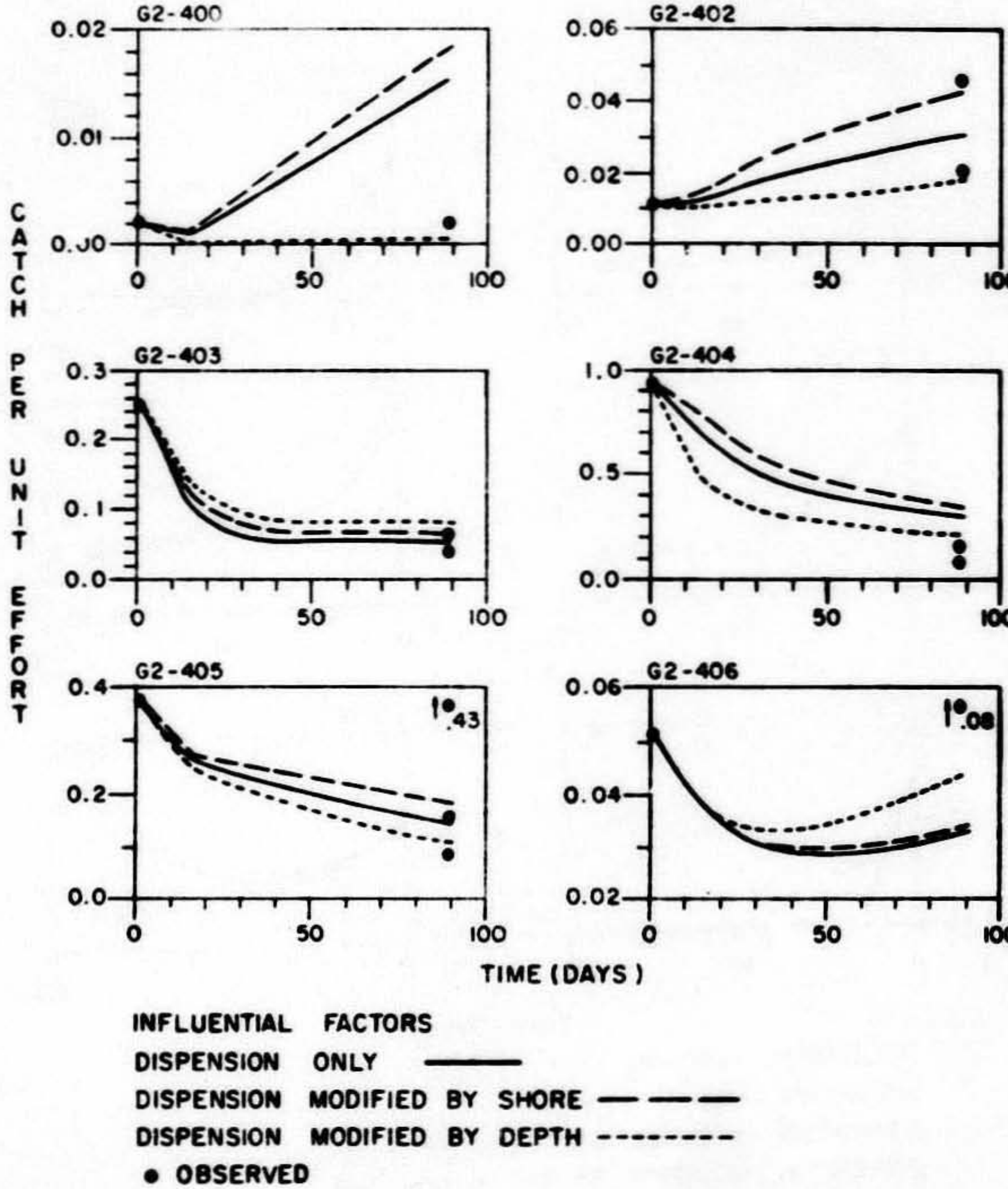

Figure 6. Calculated catch-per-unit-effort of longnose suckers at the sampling stations using the three different scenarios.

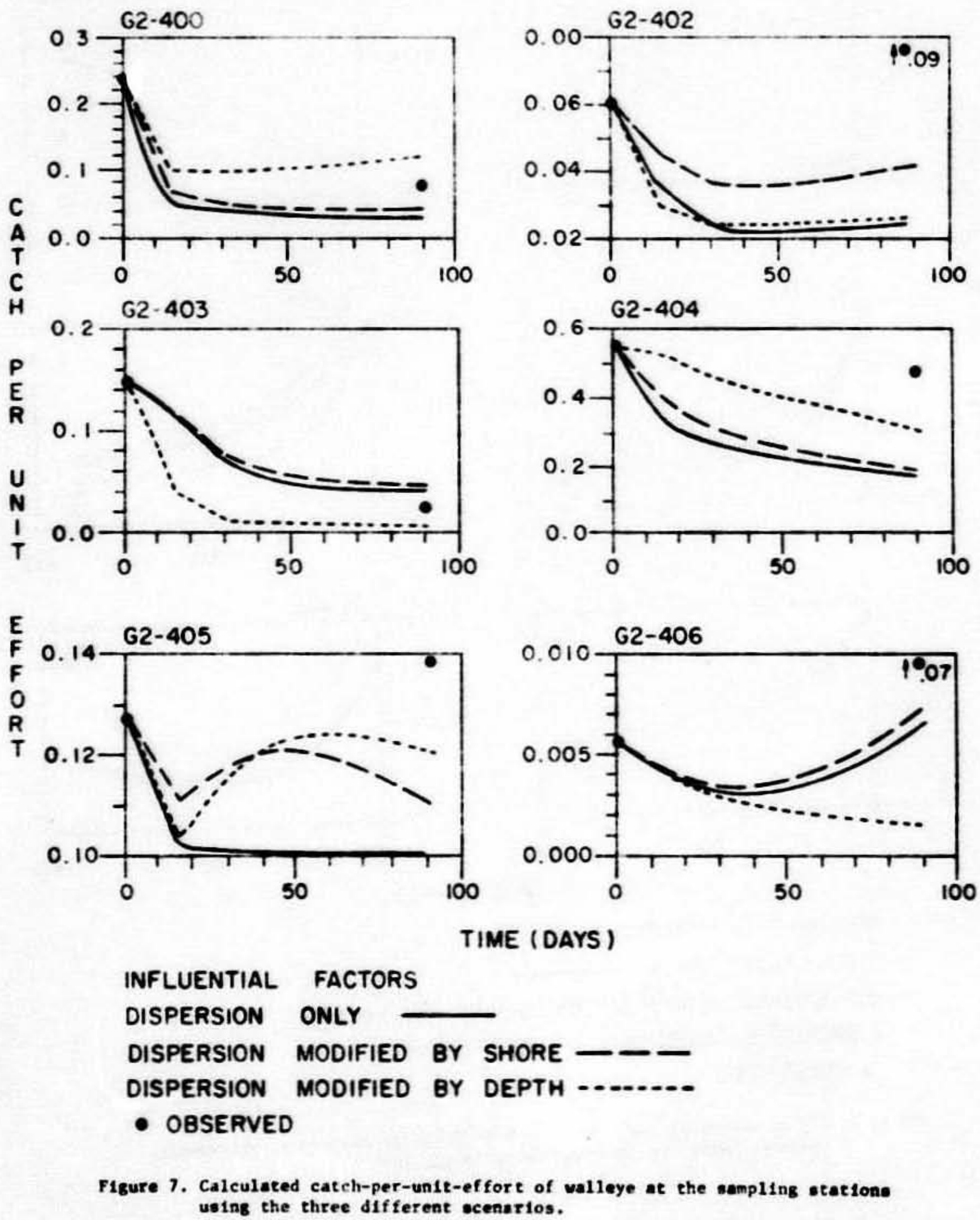

Figure 7. Calculated catch-per-unit-effort of walleye at the sampling stations using the three different scenarios.

model. Because of the way the model is structured, it will be easy to apply to any large water body for which suitable catch-per-unit-effort data is available. This will be a significant help in interpreting changes in such data where before such interpretation was, to say the least, difficult.

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