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High Latitude Marine Reserve Research in Glacier Bay National Park

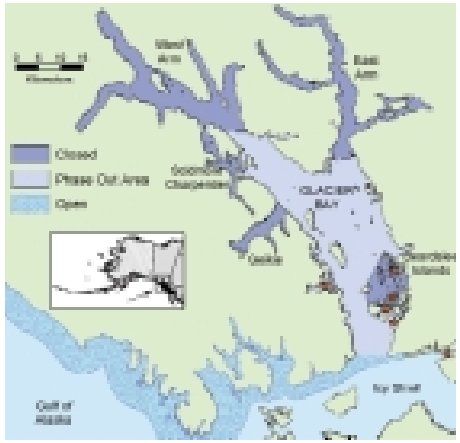

Figure 1: The open, closed, and phase-out areas for commercial fishing in Glacier Bay National Park and Preserve. The red stars represent study locations for the long-term study monitoring changes in the Dungeness crab population before and after commercial fishing.

Left: There has been a dramatic shift in the size of male Dungeness crabs following the closure of commercial fishing in Glacier Bay National Park.

By S. J. Taggart, J. Mondragon, A. G. Andrews, J. K. Nielsen

Glacier Bay National Park and Preserve is dominated by the marine waters that make up nearly one-fifth of the park's area. Since the late 1800s, the nutrient rich waters of Glacier Bay have supported highly productive commercial fisheries. Congress closed fishing in parts of Glacier Bay National Park in 1999, creating one of North America's largest marine reserves. Throughout the world, marine reserves are being promoted as effective tools for managing fisheries while simultaneously meeting marine conservation goals and maintaining marine biodiversity. Increases in individual size, density, biomass, and diversity have been demonstrated in studies of fish and invertebrates from both temperate and tropical marine reserves *(Halpern 2003)*. Studies on the effectiveness of marine reserves at high latitudes, however, are rare. The formation of marine reserves in Glacier Bay National Park provides a unique opportunity for marine reserve research in a high latitude ecosystem.

The legislation that closed commercial fishing in the park specifies the species and the areas that will be protected. All commercial fishing was left open in a three-mile band of water adjacent to the park's shore along Icy Strait and the Gulf of Alaska, while it was closed in Glacier Bay proper *(Figure 1)*. Commercial fishing for Tanner crab *(Chionoecetes bairdi)* and Pacific halibut *(Hippoglossus stenolepis)* was immediately closed in five areas that vary in shape and range in size from 40 to 280 km^2. In the central part of the bay, fishing is being phased out through a grandfather clause, which allows fishermen to continue fishing in the central part of the bay for Tanner crab, salmon, and Pacific halibut. Over the next several decades, as fishermen retire, Glacier Bay proper will become a single large reserve for all species. For red king crabs *(Paralithodes camtschaticus)* and Dungeness crabs *(Cancer magister)* the legislation immediately closed commercial fishing in all of Glacier Bay proper.

Thus, for the immediate future, there is a reserve network of five closed areas for Tanner crabs and halibut, while the entire bay is a reserve for red king crabs and Dungeness crabs. The network of closed areas adjacent to the open portion of the bay provides a large-scale laboratory to study marine reserve effectiveness. The marine reserves in Glacier Bay are changing the protected populations beneath the waters in ways that we are just beginning to see.

To manage the marine resources and understand marine reserve processes in Glacier Bay, the U.S. Geological Survey (USGS), with support from the National Park Service (NPS), is conducting research in order to answer some fundamental questions. First, since the reserves only protect the animals that reside within the boundaries of the protected area, we need to know the distribution and abundance of resources in each reserve. Secondly, it is important to understand how animals are moving in relation to the reserve boundaries and how much time they are spending in the protected areas. If animals are spending a significant portion of time inside the reserves, then we may start to observe some of the population changes,

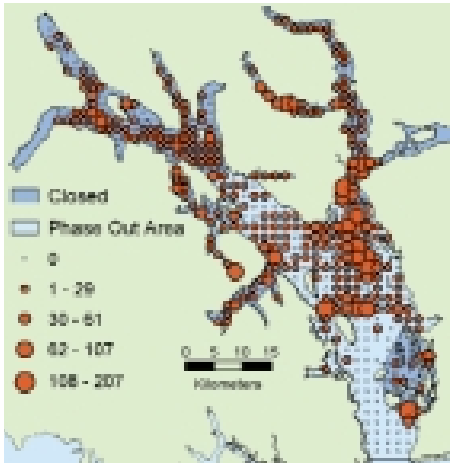

Figure 2: The catch per pot (or Catch-Per-Unit-Effort) of Tanner crabs throughout Glacier Bay.

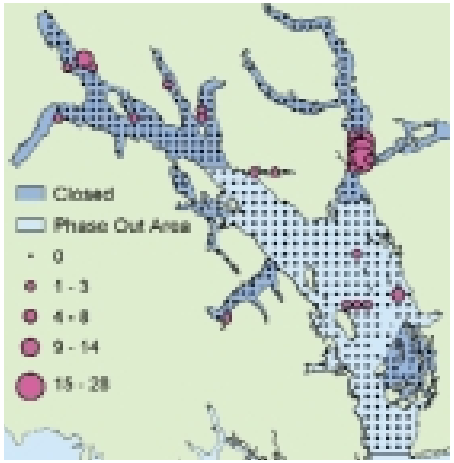

Figure 3: The catch per pot (or Catch-Per-Unit-Effort) of red king crabs throughout Glacier Bay.

such as higher abundance, that have been demonstrated in protected areas in other parts of the world.

Distribution and Abundance of Fisheries Resources in Reserves

In 1999 researchers conducted a pot survey to determine the distribution and relative abundance of Dungeness crabs throughout Glacier Bay. Although Dungeness crabs occurred throughout the park, they were very rare in the northern portion of the bay *(Taggart et al. 2003)*. In the summer of 2002, researchers systematically sampled for Tanner and red king crabs throughout Glacier Bay. Sampling occurred on a one mile (1.6 km) grid blanketing the entire bay. From this sampling, estimates of the relative abundance and size frequency of the crabs inside and outside of the newly created reserves were made. Tanner crabs were widely distributed and their density was approximately equal in the closed and open areas *(Figure 2)*. On the other hand, their distribution varied widely between protected areas; the majority of the Tanner crabs in the protected areas were in two reserves. In addition, two of the reserves had areas where juvenile Tanner crabs were abundant and thus might be potential nursery areas. In contrast to Tanner crabs, red king crabs were highly aggregated, and 73% were in a small part of a single reserve *(Figure 3)*.

These studies illustrate that basic systematic sampling could provide vital information on where future marine reserves should be located and that reserves in close proximity to each other may have very different relative abundances of animals. Knowing there are areas with high relative abundance inside the reserve boundaries is the first step. The next step is to determine the movements of the population in relation to the reserve boundary.

Tanner and King Crab Movement in Marine Reserves

We have initiated a research program to measure how often breeding adults enter and leave the protected areas. Our long-term vision is to simultaneously measure the transfer rate among multiple reserves and the adjacent area remaining open to commercial fishing. Red king crabs, Tanner crabs, and Pacific halibut will be sonic-tagged within each of the reserve areas and the area open to fishing, and their movements will be detected by strings of submersible data loggers that create acoustic gates along the reserve boundaries.

In September 2002, we initiated the research by tagging 21 Tanner crabs and 16 king crabs in the East Arm reserve and installing a string of data loggers along the boundary. The data loggers are recording tagged animals that move across the reserve border. We have relocated tagged crabs every two to three months since being released by visiting a series of grid stations and systematically searching with underwa-

A USGS researcher releases a tagged king crab into the East Arm marine reserve in Glacier Bay National Park.

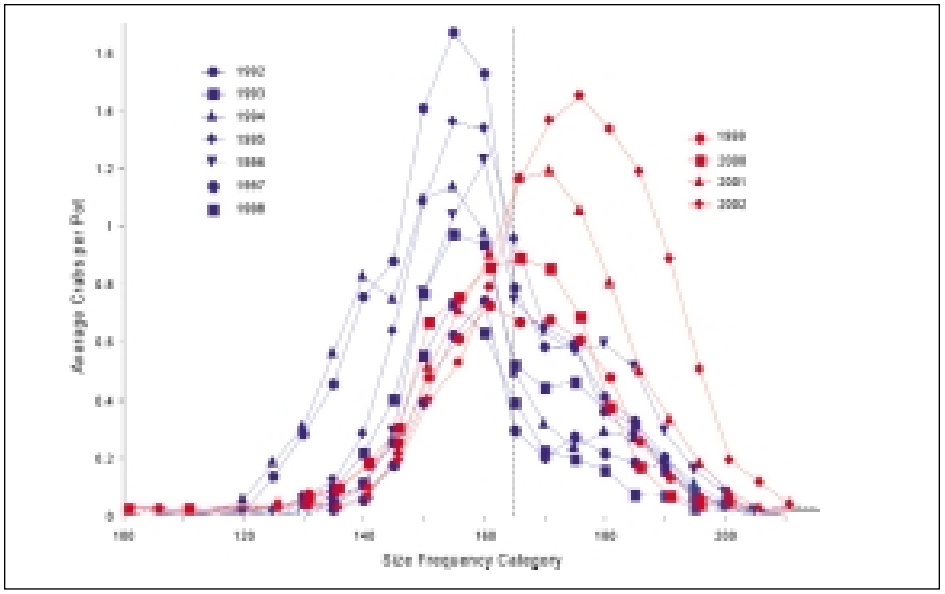

Figure 4: Average size abundance distribution for male Dungeness crab at all sites closed to commercial fishing. Each line represents a year from 1992 to 2002; blue lines are years before commercial fishing closed, and the red lines are the years after fishing closed. the dashed line shows the legal size limit (165mm) for male Dungeness crab.

ter hydrophones. Tanner crabs have shown large variation in the distance that they move. A few individuals have been relocated in the same area, but one male has traveled at least 32.5 km since it was released. The king crabs were highly aggregated when they were tagged, and they have tended to move as a group. To date, three of the male Tanner crabs have moved across the reserve boundary, and one male and one female king crab have been located on the boundary.

We will continue to track these crabs over the next two years to estimate how much time the population spends in the reserve and determine the transfer rate across the boundary. This study will enable us to evaluate the effectiveness of the East Arm marine reserve and develop predictions about long-term changes in the Tanner and king crab population demographics inside the reserve. If the transfer rate is low, then we would expect to see increases in body size and or population abundance in the reserve.

Knowing there are areas with high relative abundance inside the reserve boundaries is the first step. The next step is to determine the movements of the population in relation to the reserve boundary.

Researchers attach a sonic tag to a Tanner crab in order to study the movement of animals inside a marine reserve in Glacier Bay National Park.

The number and size of male Dungeness crabs increased dramatically after the 1999 closure of Glacier Bay to commerial fishing.

Changes in size of Dungeness crab after fishing closure

In anticipation of commercial fishery closures, scientists from the U.S. Geological Survey, the University of Alaska Fairbanks, and the National Marine Fisheries Service initiated a study in 1992 to document changes in the population structure of Dungeness crabs. Study sites were selected both inside and outside the proposed closure areas and sampled with commercial pots and scuba transects *(Figure 1)*. Since 1992, we have collected seven years of pre-closure and four years of post-closure data.

After the 1999 closure of Glacier Bay to commercial fishing, the number and size of male Dungeness crabs increased dramatically *(Taggart et al. In Press) (Figure 4)*. Harvest regulations allow only large male Dungeness crabs to be removed by the fishery. Therefore, one would expect changes to occur more quickly among the male crab population. During the pre-closure phase of the study, the number of male crabs over 165 mm (legal size) was relatively small compared to the number of sub-legal sized males. After the fishery closure, the number of male crabs over 165 mm began increasing, and by 2000, the number of crabs larger than 170 mm exceeded the highest abundance we had recorded during any of the 7 pre-closure years. This trend continued, and in each subsequent year since the closure, the number and size of male crabs increased. In contrast, at a control site outside of the park that is still open to commercial fishing, there was not a large shift in the size of male crabs. At

all sites, female and sub-legal sized male crabs, the portions of the population not directly targeted by commercial fishing, did not increase in size or abundance following the closure.

Our data demonstrate that a marine reserve can markedly increase the size of male Dungeness crabs. Fisheries that remove most of the large individuals from a population can select against genotypes that promote fast growth *(Reznick et al. 1990)*, and slower growth can reduce productivity of fisheries *(Conover and Munch 2002)*. If reserves protect adult animals so they have the opportunity to grow to a larger size, and there is gene exchange between the reserve and the adjacent area, the genetic consequences of commercial fishing could potentially be mitigated by strategically located marine reserves *(National Research Council 2001; Trexler and Travis 2000)*. The results of our research in Glacier Bay support the concept that marine reserves could help maintain genetic diversity in Dungeness crabs and other crab species subjected to size limit fisheries.

Implications

Controlled experiments testing the impact of human exploitation on the population structure of marine species are rare and even more unusual for crustaceans. Closures of fisheries are usually prompted by major declines in the abundance of the harvested species resulting in the collapses of the fishery *(Jackson et al. 2001)*. In Alaska, such closures for crustaceans normally remain in effect only until there is evidence that the stocks are rebounding *(Orensanz et al. 1998);* so there are limited opportunities to compare changes in the populations of a closed area with nearby populations still being exploited. The ongoing marine reserve research in Glacier Bay will provide valuable information to managers, scientists, and the public to evaluate the utility of reserves as a management tool for solving local, national, and global marine conservation issues.

Acknowledgments

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