Testing the Effectiveness of a High Latitude Marine Reserve Network: A Multi-Species Movement Study

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Abstract. In 1999, the U.S. Congress closed commercial fishing in parts of Glacier Bay National Park, Alaska, and effectively created one of America's largest temperate marine reserve networks. This closure provided an opportunity to test the effectiveness of a high latitude marine reserve. The retention of breeding adults in marine reserves is quantified in simulation models as transfer rate. These models demonstrate that transfer rate is central to reserve effectiveness. In 2002, we initiated a study to measure the transfer rate of king and Tanner crabs between the East Arm reserve and the adjacent area remaining open to commercial fishing. We tagged 31 male Tanner crabs and 27 red king crabs with ultrasonic tags. In August 2004, 29 percent of the tagged Tanner crabs had crossed the East Arm reserve boundary. We found that Tanner crabs demonstrated wide variation in movement patterns among individuals, with some individuals moving large distances. In contrast, red king crabs displayed coordinated movements on an annual cycle and, except for one individual, have not been found outside of the East Arm reserve.

Introduction

In 1999, commercial fishing for Tanner crabs (*Chionoecetes bairdi*) was closed in five distinct areas of Glacier Bay that vary in shape and range in size from 40 to 280 km^2 (fig. 1). A grandfather clause allows fishermen to continue fishing in the central part of the Bay for Tanner crabs, but over the next several decades, as fishermen retire, Glacier Bay will become a single large reserve for all species. For red king crabs (*Paralithodes camtschaticus*) the legislation immediately closed commercial fishing in all of Glacier Bay in 1999. Thus, for the immediate future, there is a reserve network of five closed areas for Tanner crabs while the entire Bay is a reserve for red king crabs. To improve our insight into marine reserve design we chose to treat both king and Tanner crabs as having the same network of closures. The network of closed areas adjacent to the open portion of the Bay provides a large-scale laboratory to study marine reserve effectiveness.

Reserve size and shape can greatly influence the ability of a marine reserve to protect adult breeding populations (Polacheck, 1990; Demartini, 1993; Guenette and Pitcher, 1999). To be effective at protecting breeding adult populations, a marine reserve must be large enough to protect a sufficient proportion of the population for positive effects such as increased body size, density, or fecundity to be realized (Polacheck, 1990). A small boundary to reserve area ratio can result in lower movement across the reserve boundary, and thus increase the spawner stock biomass in the reserve, and shift the age structure of the population to older individuals.

The goal of this project was to test the effectiveness of the marine reserves in Glacier Bay by understanding how animals are moving in relation to the reserve boundaries and how much time they are spending in the protected areas. We are using a combination of ultrasonic gates and ultrasonic tags to measure the transfer rate of adult Tanner and red king crabs between the East Arm reserve and the adjacent area remaining open to commercial fishing for Tanner crab. If animals are spending a significant part of time inside the reserves, then we may start to observe some of the population changes, such as higher abundance, that have been demonstrated in protected areas in other parts of the world.

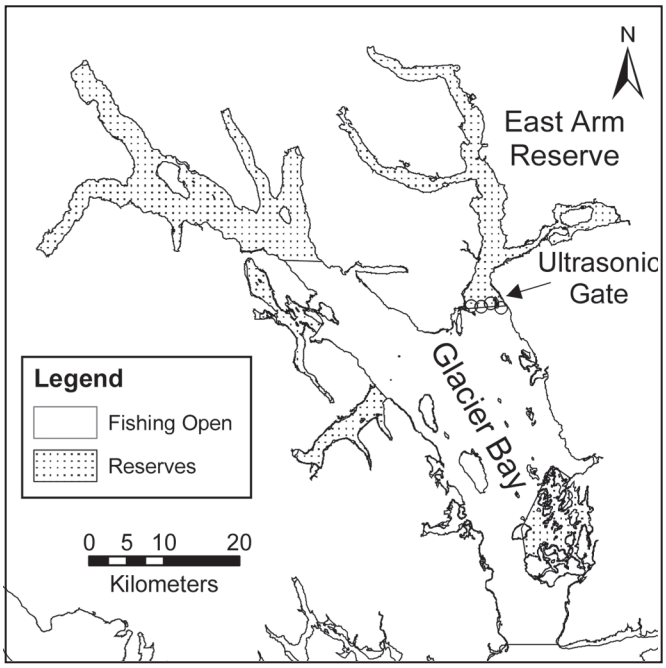

Figure 1. Map showing the marine reserve network of five closed areas for Tanner crab commercial fishing. The entire area in Glacier Bay closed in 1999 for king crab. An ultrasonic gate was installed at the entrance the East Arm reserve to monitor movement between the reserve and adjacent area remaining open to commercial fishing.

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Methods

In September 2002 and October 2003, ultrasonic transmitters manufactured by Lotek Wireless, Inc., were attached to the carapace of a random sample of the mature part of the Tanner and red king crab populations inside the East Arm reserve. Tags were attached proportionally to the adult crab populations in the study area. The tags have an expected operational life of 3 years and include activity sensors to determine if the crab molted its carapace (with the tag) or died. We did not tag females because female Tanner crabs are small and the tags were too large for these individuals. Thirty-one tags were attached to Tanner crabs and 27 were attached to red king crabs over a 2 year period (table 1).

Tagged crabs were located with a Lotek tracking receiver with an omni-directional hydrophone deployed from USGS R/V *Alaskan Gyre*. Tagged crabs were located by systematically listening at stations 0.75 km apart. Searches were conducted approximately four times per year. We also tested a towed hydrophone as an alternative method for locating tagged crabs. During February 2004, we towed an omni-directional hydrophone 20 m below the surface at 8km/hr. At 8 km/hr, we were able to decode tags up to 700 m away. Since February 2004, towed hydrophone searches along band transects have replaced systematic listening station searches.

In November 2002, an ultrasonic gate was constructed by mooring four Lotek submersible dataloggers along the boundary of the East Arm reserve (fig. 1). The spacing of the dataloggers allowed for the entire opening of the East Arm reserve to be monitored. The dataloggers recorded the tagged crabs' individual identification, the date and time detected, and the activity sensor data. Dataloggers were suspended 20 meters from the bottom with subsurface flotation.

Table 1. Number of crabs tagged in September 2002, and October 2003, in the East Arm reserve.

Year tagged	Tanner crab	Red king crab	
	Male	Male	Female
2002	21	8	8
2003	10	11	0
Total	**31**	**27**	

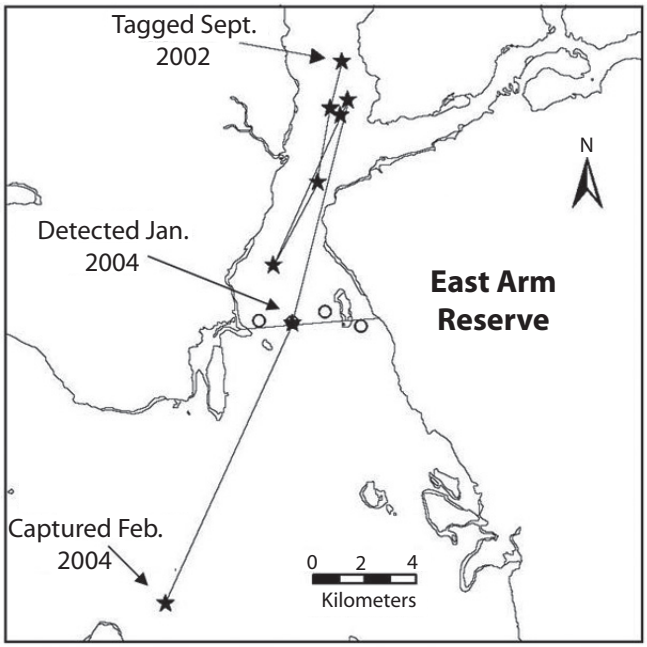

Figure 2. Tanner crab locations in the East Arm reserve, 2002–2004. Stars represent the locations of a Tanner crab tagged in the East Arm reserve and captured in the commercial fishery in the central Bay 17 months later. Small circles indicate the location of the ultrasonic gate at the entrance of the East Arm reserve.

Results

Of the 31 male Tanner crabs we tagged, a total of 9 Tanner crabs (or 29 percent) have crossed the East Arm boundary. Four of these nine crabs were detected by the gate and also were located outside the boundary with manual tracking; one of these crossed back into the East Arm reserve. Four of the nine crabs that crossed the boundary were found outside the ultrasonic gate with manual tracking only; these crabs probably missed detection due to datalogger malfunctions. One animal that crossed the boundary was detected by the gate on January 20, 2004, and was captured in the commercial fishery on February 17, 2004; traveling a straight-line distance of 12 km in 28 days (fig. 2). Nineteen of the male Tanner crabs have been relocated only inside the East Arm reserve. These individuals display a high variability in distance traveled. One example is a crab that was tagged in 2002 in upper Muir Inlet, approximately 6 km from Muir Glacier. This individual was detected by the gate in December, 2003, which means that it traversed the full length of the East Arm reserve. Subsequently, it was located inside the East Arm reserve in February 2004. Two of the crabs tagged in 2002 have not been detected since they were released. One of the crabs tagged in 2003 was detected once inside the East Arm reserve and once at the gate, but has not been detected again.

In contrast to the Tanner crabs, the 27 tagged red king crabs have moved from their release locations to subsequent locations and maintained an aggregated distribution during winter and spring. During two manual tracking surveys conducted in November 2002 and 2003, the king crabs were located north of Adams Inlet and were aggregated; during February 2003 and 2004, they were located near the entrance of the East Arm reserve and they were again aggregated (fig. 3). Only one red king crab has crossed the East Arm reserve boundary. In the early and late summer months, fewer crabs were detected and those that were relocated were less aggregated. These crabs were relocated between the winter and spring sites. Seven of the eight female king crabs moved

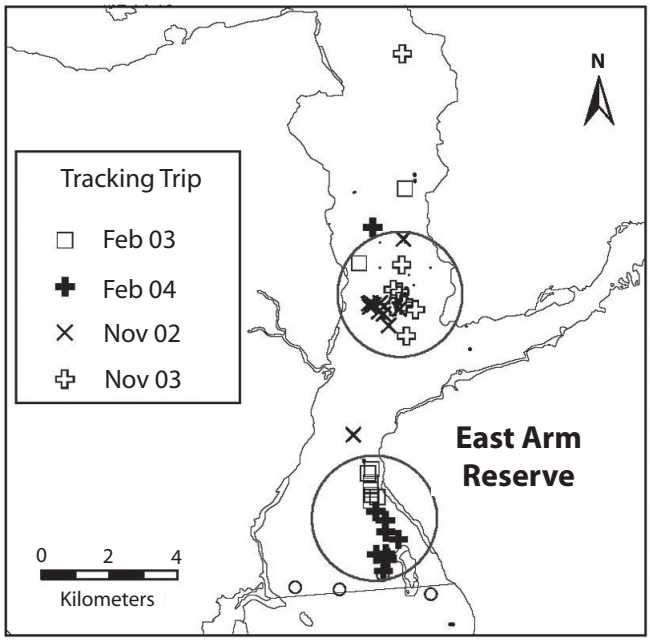

Figure 3. East Arm reserve at Adams Inlet displaying the two areas of high seasonal use by red king crab. Large circles highlight areas. Small circles indicate the location of the ultrasonic gate at the entrance of the East Arm reserve.

to the entrance of the East Arm reserve and many have been relocated at this location and display no activity (i.e., crab molted it's carapace or died).

Discussion and Conclusions

The combination of the ultrasonic gate and towed hydrophone searches made it possible to estimate the movements of crabs at a population level. Our data of Tanner crab movement demonstrate that there is large variation in distance and direction traveled among individual crabs. Three of the crabs tagged in 2003 moved to the mouth of the East Arm and were detected by the ultrasonic gate. These data demonstrate that Tanner crabs are able to move considerable distances in a short time and support the hypothesis that crabs not detected since their release in 2002 may have left the East Arm reserve before the ultrasonic gate was functional. Therefore, the number of tagged Tanner crabs detected crossing the boundary may be an underestimate of the actual number that crossed. Tanner crab movements encompassed an area larger than the East Arm reserve; therefore, the East Arm reserve may not adequately protect the Tanner crab population. Further research would be beneficial to address the movements of Tanner crabs in relation to the entrance of Glacier Bay to determine how the Bay as a whole will protect Tanner crabs.

Multi-year relocations of tagged king crabs demonstrate that the crabs migrate seasonally between the area north of Adams Inlet and the entrance of the East Arm reserve. Seven of the eight tagged females presumably molted their tags at the entrance of the East Arm reserve. This suggests that this area may be an important reproductive habitat because female king crabs molt their exoskeletons before mating and extruding eggs. It is inconclusive where the king crabs reside during the summer and whether they maintain an aggregated distribution as they move seasonally between Adams Inlet and the entrance of the East Arm reserve. Coordinated movements of adult king crabs have been previously documented in Auke Bay, Alaska (Stone and others, 1992). Our findings in Glacier Bay may have important management implications in the southeast Alaska fishery. For example, it may be feasible to close relatively small areas to the commercial fishery to protect important aggregations of adult king crabs.

Acknowledgments

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References Cited

Demartini, E.E., 1993, Modeling the potential of fishery reserves for managing Pacific coral reef fishes: Fishery Bulletin, v. 91, p. 414-427.

Guenette, S., and Pitcher, T.J., 1999, An age-structured model showing the benefits of marine reserves in controlling overexploitation: Amsterdam, Fisheries Research, v. 39, p. 295-303.

Polacheck, T., 1990, Year round closed areas as a management tool: Natural Resource Modeling, v. 4, p. 327-354.

Stone, R.P., O'Clair, C.E., and Shirley, T.C., 1992, Seasonal migration and distribution of female red king crabs in a southeast Alaskan estuary: Journal of Crustacean Biology, v. 12, no. 4, p. 546-560.

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