Figure 1: Sea otters are in the first stages of recolonizing Glacier Bay. The red circles represent subtidal clam sites.

Sea Otter photos courtesy of Randall Davis © 2003

Kelp Forest photo courtesy of U.S. Geological Survey

Return to Glacier Bay

By James L. Bodkin

Introduction

A sound unheard for centuries is once again resonating above the turbid waters of Glacier Bay. The sound is one of rock hammering against clam in rapid-fire succession and it signals the return of the sea otter *(Enhydra lutris)* to its former habitats in Southeast Alaska. The sound also signals the beginning of a process that will, with little doubt, result in profound and persistent changes in the marine communities of Glacier Bay. Some of these changes are predictable, while others will be unanticipated. Without understanding the range of effects of sea otters, management of many marine resources may be severely impaired for decades to come. Fortunately, because sea otters are easily observed and their prey easily studied, methods and approaches to studying sea otters and their ecology are perhaps better developed than for any other marine mammal *(Riedman and Estes 1990)*.

For several reasons Glacier Bay National Park and Preserve provides an excellent laboratory for studying the effects of sea otters on marine communities. First and foremost, sea otters are in the early stages of recolonizing Glacier Bay. This provides the opportunity to describe the marine community, as it exists before sea otters exert their influence, and to document how the community changes as sea otters become established. Because Glacier Bay is large, it will take many years for sea otters to reoccupy all habitats in the bay. The opportunity to compare similar habitats in Glacier Bay, both with and without sea otters, and before and after sea otter colonization, provides an experimentally powerful design. This can then allow researchers to assign cause based on observed change *(Figure 1)*. In addition, the protected waters of Glacier Bay provide a laboratory that is, and will likely remain, relatively unaffected by human activities such as contamination, fishing, logging, and mining, which could potentially confound the interpretation of ecological study. It was under consideration of these attributes that we began our work nearly ten years ago to understand the effects of sea otters on the structure and function of near-shore marine communities in Glacier Bay.

The Decline and Recovery

At the end of the nineteenth century along nearly the entire shore of the North Pacific Ocean, the sound of sea otters foraging could no longer be heard. This was the result of a commercial fur harvest that began about 1750 and ended in 1900 with the near extinction of the species *(Kenyon 1969)*. The first efforts to conserve sea otters occurred in 1911. At that time sea otters received their first protection under the International Fur Treaty, and likely numbered just several hundred animals scattered in 11 populations between central California and Russia, with most individuals occurring in the Aleutian Islands. No sea otter populations persisted between Prince William Sound in Alaska and the Big Sur coast of California. During the twentieth century, extant sea otter populations exhibited a general pattern of recovery, with growth rates from about 5% to 13% per year and displaying concurrent patterns of range expansion *(Bodkin et al. 1999)*.

The next efforts to conserve and aid in the recovery of sea otter populations began in 1965 and consisted of translocations from Amchitka Island and Prince William Sound in Alaska to Oregon, Washington, British Columbia, and Southeast Alaska *(Jameson et al 1982)*. Between 1965 and 1969, 412 sea otters arrived at several loca-

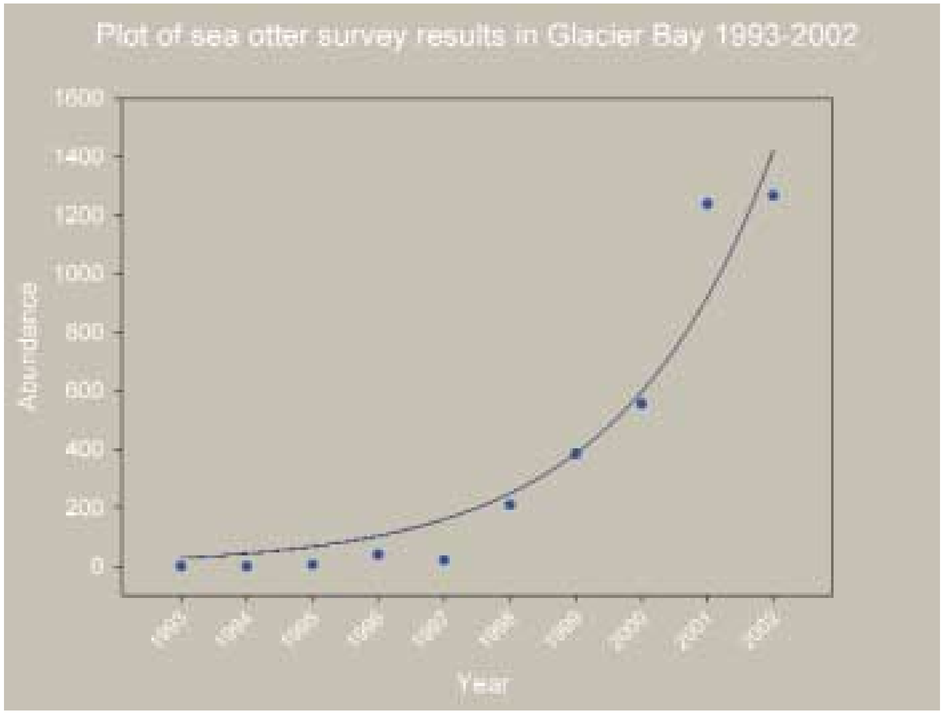

Figure 2: Since 1993, sea otter populations have increased dramatically.

Photo courtesy of U.S. Geological Survey

Figure 3: A diverse assemblage of animals reliant on the kelp forest characterize the kelp forest community.

Where sea otters are present, they effectively limit the abundance of sea urchins by actively consuming individuals larger than about one inch in diameter. As a result of this predation on urchins, which limits urchin size, abundance, and mobility, urchins do not have a large grazing effect and consequently kelp forests flourish.

tions in Southeast Alaska, including areas adjacent to Glacier Bay National Park and Preserve in Cross Sound. Although surveys of sea otter populations in Southeast Alaska were infrequent, results through at least 1988 indicated that the population was increasing about 20% annually with simultaneous expansion of range *(Pitcher 1989)*. By 1988 sea otters were common in Cross Sound and immigration into Icy Straits was evident. In 1993 the first sea otters were observed in Glacier Bay, although annual surveys indicate permanent residence was not established until 1998. Since that time, population growth in Glacier Bay has been phenomenal. It is almost certainly exceeding the reproductive potential of the species, and thus likely representing contributions from both births and immigration from outside the bay. *(Figure 2)*.

A "Keystone" Species

Our understanding of the role sea otters will play in modifying the Glacier Bay marine ecosystem will benefit from previous studies of the effects of sea otter foraging in other locales *(Estes and Palmisano 1974, Simenstad et al. 1978, Kvitek and Oliver 1988, Kvitek et al. 1992)*. Probably the best example of sea otter effects comes from the description of sea otters as ecological "keystone" species in kelp forest communities of the coastal North Pacific Ocean *(Estes and Duggins 1995)*. Within these shallow rocky habitats occur several species of sea urchin *(Stronglycentrotus sp.)*, marine herbivores that actively graze on algae. This includes the brown algae that often forms the conspicuous and productive kelp-forests that exist along many coastlines. Where sea otters are present, they effectively limit the abundance of sea urchins by actively consuming individuals larger than about one inch in diameter. As a result of this predation on urchins, which limits urchin size, abundance, and mobility, urchins do not have a large grazing effect and consequently kelp forests flourish. In turn, kelp forests provide habitat, refuge, and forage for a complex community of invertebrates, fishes, birds, and mammals. A high biomass of kelps and a diverse assemblage of animals reliant on the kelp forest characterize the kelp forest community. *(Figure 3)*.

Photo courtesy of U.S. Geological Survey

Figure 4: Urchin barren.

Alternatively, when sea otters are

absent, urchin populations respond to reduced predation by increased abundance and average size. As this happens, the level of grazing by urchins increases, which can eventually eliminate the forest and much of the associated animal community that is supported by the kelp forest. This urchin-dominated community is commonly referred to as an "urchin barren." It is characterized by large and numerous sea urchins, little algae or canopy-forming kelp forests, and the reduction or absence of kelp-associated fauna. *(Figure 4)*. Additionally, in the absence of sea otter predation, some of the other preferred prey species, such as abalone *(Haliotis sp.)*, crab *(e.g., Cancer sp.)*, and mussels *(Mytilus sp.)*, can also increase in abundance and average size *(Lowry and Pearse 1973, Garshelis et al. 1986, VanBlaricom 1988)*.

Although habitats suitable for supporting kelp forests exist in Glacier Bay, much of the shallow water habitats in Glacier Bay are soft-sediment, such as mud, sand, gravel and cobble that will not provide optimum substrate for kelp forests. We can expect the transformation of some urchin barrens into kelp forests. In order to determine what kinds of direct and indirect effects can be anticipated as sea otters occupy and forage in these soft-sediment marine communities, the U.S. Geological Survey's Alaska Science Center, in cooperation with Glacier Bay National Park and Preserve, initiated a program consisting of three integrated avenues of research. The first consists of documenting the distribution and abundance of sea otters in and around Glacier Bay and how that changes over time (see above). The second consists of describing the diet of recolonizing sea otters; identifying species, number and size of prey; and describing the diet as it changes. The third component of our program consists of estimating the density, sizes, and composition of species occurring in intertidal and subtidal habitats, before and after sea otter recolonization. The third part focuses initially on those species that sea otters consume directly.

The Diet of Glacier Bay Sea Otters

To date we have observed the results of more than 3,000 sea otter foraging dives in Glacier Bay *(Bodkin et al. 2001, 2003)*. The primary data that we collect while observing feeding sea otters includes: success or failure, and species, number and sizes of prey consumed. *(Figure 5)*. Sea otters successfully recover one or more prey on about 85% of their foraging dives in Glacier Bay. Although the number of prey types consumed by sea otters exceeds 150 species *(Estes and Bodkin 2001)*, the bulk of their diet can be classified into the general taxonomic groups of bivalve mollusks (clams and mussels), echinoderms (sea urchins

Photograph courtesy of U.S. Geological Survey

Figure 5: Researcher observing sea otter foraging dives.

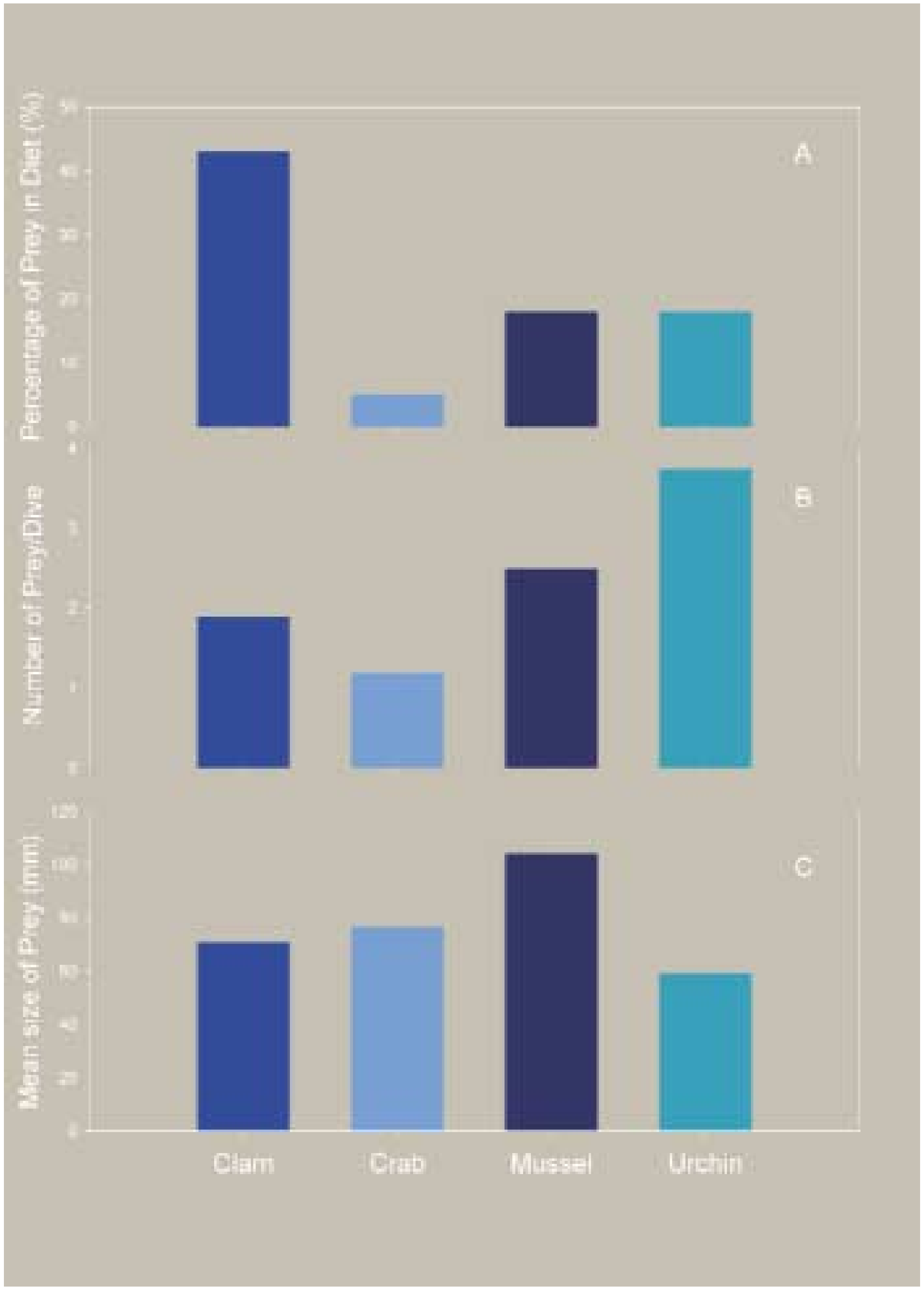

Figure 6: Sea otter diet composition (A), number of prey (B) and mean size of prey in mm (C) in Glacier Bay, Alaska, 1993-2002

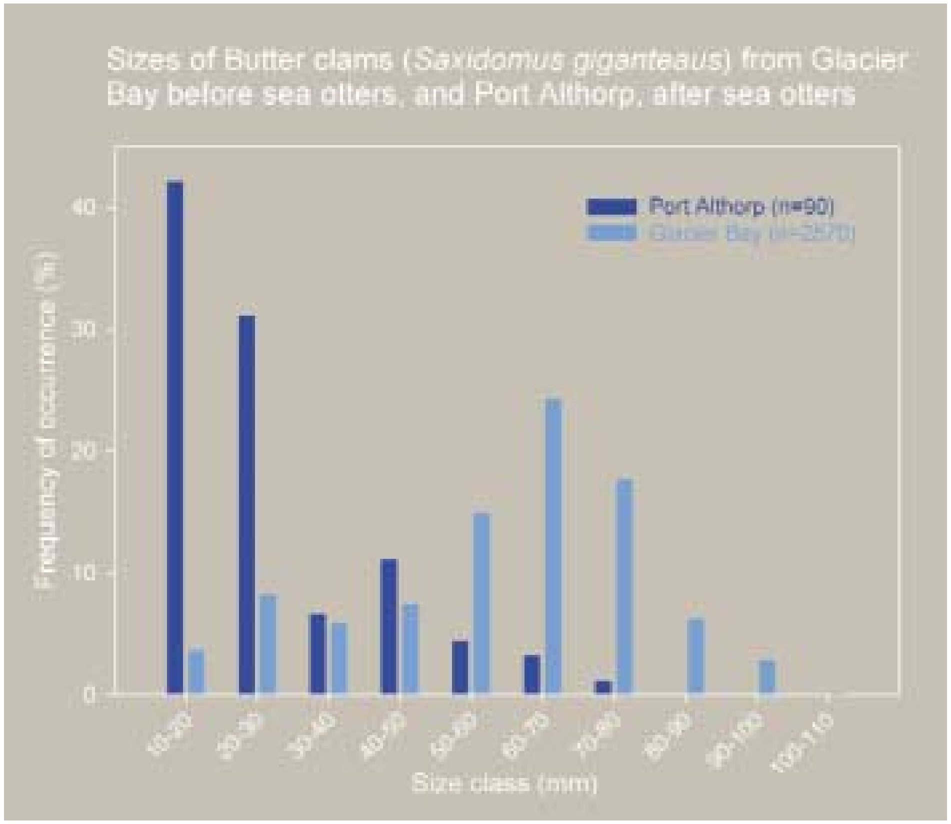

Figure 7: Dramatic declines in the size of butter clams have been observed.

Photograph courtesy of Randall Davis © 2003

and stars), and crustaceans (crabs). Although the diet we observed in Glacier Bay varies within the area occupied by sea otters, it consists largely of invertebrates that reside in, or on, unconsolidated substrates such as mud, sand, gravel and cobble. Over all areas, bivalve clams (species of *Mya*, *Saxidomus*, *Protothaca* and *Serripes*) constitute 43% of the observed diet, urchins (*S. droebachiensis*) 18%, horse mussels (*Modiolus modiolus*) 18%, and crabs (species of *Cancer*, *Telmessus*, *Chionoecetes* and *Paralithoides*) 5%. *(Figure 6)*. Relatively rare species include octopus *(Octopus dofleini)*, snails *(Fusitriton oregonensis and Neptunea sp.)*, the fat innkeeper worm *(Echiurus sp.)*, the basket star *(Gorgonocephalus caryi)*, and the sea cucumber *(Cucumaria fallax)*.

Effects of Sea Otters on Clam Populations

Because sea otters have not resided in large numbers for a long period at our study sites in Glacier Bay, we were unable to compare our measures of prey populations before and after sea otter recolonization. As an approximation of changes we might expect in Glacier Bay, we have compared clam populations before sea otters arrived in Glacier Bay to a nearby and similar area in Port Althorp, where sea otters have been present for about 20 years. *(Figure 7)*. Although we have sampled crabs, mussels, urchins and other otter prey in Glacier Bay, the following example from our subtidal clam data serves as an example of the types of data obtained. In addition, through comparison with nearby Port Althorp, we can approximate what we might expect in Glacier Bay as a direct result of sea otter foraging.

Between 1998 and 2002 we sampled 13 subtidal clam beds in Glacier Bay before sea otters occupied those sites. For comparison, in nearby Port Althorp where sea otters have been foraging for more than 20 years, we sampled an additional 5 sites. We selected the sites based on the presence and high abundance of clam siphons in Glacier Bay and based on sea otter foraging and fresh clam shell fragments in Port Althorp. We used a diver-operated suction dredge to excavate 50 cm by 50 cm quadrats to depths of about 25 cm at each site to determine species composition and sizes of subtidal clams. *(Figure 8)*.

Average densities of all clams were about six times greater in our Glacier Bay sites (59 per quadrat) than at our Port Althorp sites (10 per quadrat). Densities of the butter clam *(Saxidomus gigantea)*, a large and preferred sea otter prey, were more than 10 times higher in Glacier Bay than at Port Althorp. Probably of equal or greater importance is that the average clam was much larger in Glacier Bay than in Port

… long-time residents of the community of Elfin Cove in Port Althorp observed dramatic declines in the abundance and sizes of clams concurrent with the arrival of sea otters about 20 years ago.

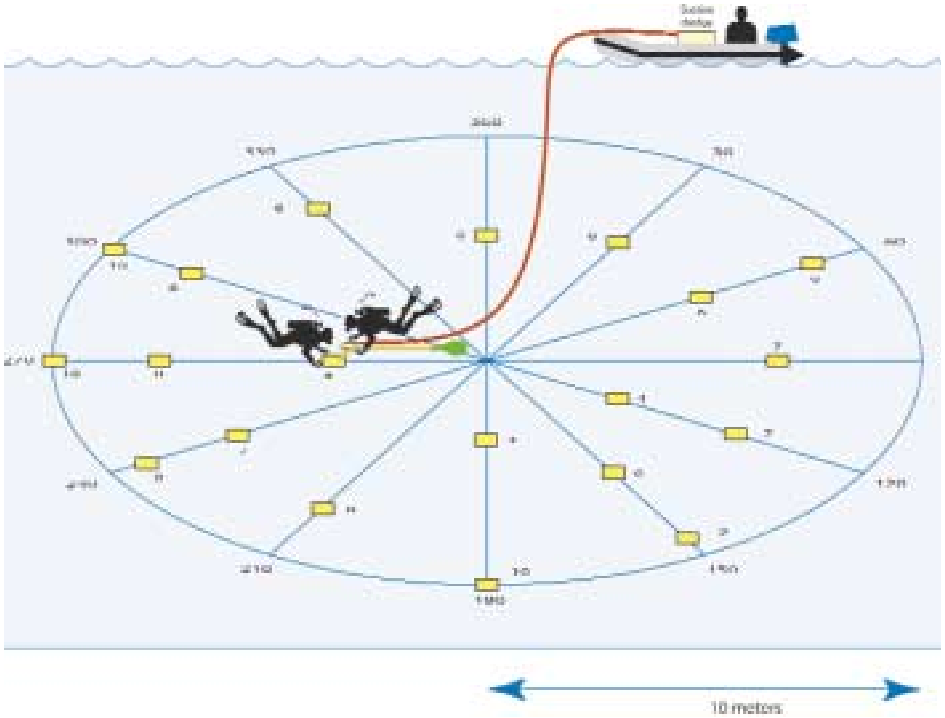

Figure 8: Schematic drawing showing excavation of quadrats utilizing the suction dredge.

Althorp: butter clams between 70 mm and 90 mm long (~3 in) were most common in Glacier Bay, compared to Port Althorp, where the majority of clams were 10 mm to 30 mm (~1 in). These differences in density and sizes resulted in estimates that placed the total butter clam biomass of the Glacier Bay sites about 75 times that of Port Althorp. Additionally, long-time residents of the community of Elfin Cove in Port Althorp observed dramatic declines in the abundance and sizes of clams concurrent with the arrival of sea otters about 20 years ago.

The pattern of higher densities and larger average sizes, of subtidal clams in Glacier Bay compared to Port Althorp, was consistent for intertidal clams, urchins, crabs, and mussels as well. These preliminary contrasts, while not unequivocal, suggest that the sea otter effect of reducing densities and sizes of preferred prey will likely also occur in Glacier Bay. Our ability to anticipate and understand both the direct and cascading effects of this predation will improve management decisions regarding marine resources in Glacier Bay. While predicting ecosystem level responses to a disturbance such as that imposed by recolonizing sea otters affords a broad suite of challenges, it also offers opportunities to advance our understanding of how these complex systems function.

Cascading Effects of Recolonization

The experimental and logistic situation offered in Glacier Bay has provided the opportunity to pursue and acquire many of the numerous data sets that will be required to document and understand the direct effects of sea otter foraging. In some cases, particularly relative to the effects of urchin removal, we will likely capture both the direct effect of reduced urchin densities and sizes, plus the cascading effect of increased algal production. However, it is also likely that other effects will be more difficult to understand, if at all. Two examples may serve to illustrate the potential breadth of effects induced by sea otter foraging.

One regards a species that is both competitor and prey for the sea otter, the octopus. Octopuses are likely near the top of the food web in Glacier Bay. We have observed "gardens" of emptied clams and other mollusks numbering into the hundreds that evidence the residence of one or more large octopuses. What will be the indirect effect on resident octopus populations of sea otters removing most of the clam biomass? What will the direct effects of otter predation on octopuses be? Reduced octopus densities may be a result. What might be the effect of reduced octopus densities on the marine communities in general?

Another example concerns several species of sea ducks that spend the winter in Glacier Bay in large numbers and who compete for many of the same prey. Sea ducks, including goldeneye *(Bucephala sp.)*, harlequins *(Histrionicus histrionicus)*, scoters *(Melanitta sp.)* and the long-tail duck *(Clangula hyemalis)*, are among the most abundant species of bird during the winter in Glacier Bay, numbering into the tens of thousands. Much of what these sea ducks forage for are bivalve mollusks, including many of those that sea otters will consume and eventually reduce in densities and average size. It is difficult to predict what the cumulative effects of reduced prey densities and sizes will be on sea ducks. On one hand, fewer clams and mussels would likely support fewer sea ducks. On the other hand, it is possible that sea otter predation will result in an increase in the abundance of smaller clams that could benefit sea ducks. Part of our challenge in preparing for the recovery of sea otter populations is

What will be the indirect effect of sea otters removing most of the clam biomass on resident octopus populations? What will the direct effects of otter predation on octopus be? Reduced octopus densities may be a result, and what might be the effect of reduced octopus densities on the marine communities in general?

Photograph courtesy of U.S. Geological Survey

Commercial, recreational, and subsistence harvest of species in Glacier Bay such as crab, urchin, and clams compete directly with sea otters, resulting in less of those prey species.

anticipating the types of direct and indirect effects that sea otters will induce.

Implications to Humans

Economically, ecologically, and culturally important marine resources will unquestionably be altered in terms of abundance and size over the coming years in Glacier Bay, as sea otters continue to recolonize former habitat. Commercial, recreational, and subsistence harvest of species such as crab, urchin, and clams clams compete directly with sea otters, resulting in less of those prey species that sea otters and humans both seek. In this context, the return of sea otters may be regarded as undesirable. Alternatively, the marine ecosystems of Glacier Bay will once again contain a top-level carnivore that was part of the evolutionary history of this marine ecosystem. As a result, the sound of the hammering rock against clam, can signify a step toward, rather than away from, an ecosystem that contains more of the components and functions of a complete ecosystem. And in this context, perhaps there is a trace of pride that we can collectively take from the return of the sea otter, that will help us strive toward the restoration, rather than continued degradation, of all ecosystems.

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