Comprehensive Management of the Wild Commercial Harvest and Mariculture of Geoduck Clams (*Panopea generosa*) in Southeast Alaska

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Abstract

The Southeast Alaska (SEAK) geoduck clam (*Panopea generosa)* fishery has expanded greatly since its opening in 1983. Existing management methodologies have failed to keep pace with the growth of the fishery, and are not equipped to address the dynamic factors that now influence the geoduck clam population and its ecosystem, including rapidly increasing predation by sea otters (*Enhydra lutris*) and a variety of physical impacts stemming from global climatic shifts, including changing water temperature and pH. As the value of wild harvest has grown, so has interest in mariculture operations in SEAK. This has led to conflicts that the existing management plan does not adequately address. In order to address these issues and a variety of other concerns, we propose several improvements to establish a comprehensive, adaptive, and ecosystem-based approach to management. We recommend conducting additional research into the overall health of, and impacts to the geoduck clam population, development of a state-operated hatchery and nursery in SEAK, more accessible paralytic shellfish poisoning testing facilities and methods, implementation of an enhancement program for the wild geoduck clam population, adjustment of the guideline harvest limits to reflect the specific needs of the SEAK geoduck populations, adoption of a new survey and harvest schedule, development of programs to encourage intertidal farming of geoduck clams, and ongoing research to determine the efficacy of our management methods in achieving sustainability in the SEAK geoduck clam fishery. We discuss the need for a management plan that addresses predation by a growing sea otter population and the difficulties associated with the establishment of such a plan. The goal of our recommendations is to develop a comprehensive, ecosystem-based approach to the management of the SEAK geoduck clam fishery that will encourage sustainable growth in the wild commercial harvest and mariculture industry while maintaining the health of the SEAK ecosystem.

Introduction

The Pacific geoduck clam (*Panopea generosa*) is a large hiatellid clam found in soft intertidal and subtidal substrates in the Northeast Pacific (Straus et al. 2009). It is important to the marine ecosystem of the outside waters of Southeast Alaska (SEAK). Geoduck clams are a food source for many organisms, including sea otters, dungeness crab, halibut, sea stars, and species of infaunal nematarian worms. They consume both suspended detritus and plankton residing within the water column. Thus, geoduck clams are an important element of a healthy trophic pyramid (Straus et al. 2009). The health of this ecosystem is essential to a tourism industry that brings millions of dollars in revenue to SEAK each year. The geoduck clam is also harvested commercially, directly connecting it to the economies of many SEAK communities. The recent rapid increase in the price of geoduck clam in foreign markets -- from $0.70/lb in 1994 to more than $10.00/lb in recent years -- has resulted in increased pressure on the resource, and has prompted conflicts over the management of the commercial fisheries, particularly between the wild commercial dive fisheries and the mariculture harvest (Prichett and Hoyt, 2008; Vadopalas, 2005). Several such conflicts were recently resolved through a series of civil lawsuits (Alaska Trademark Shellfish LLC et al. v. State of Alaska et al.). The existing management plan for the SEAK geoduck clam is inadequate, as it is based largely on research conducted in Washington (WA) and British Columbia (BC) and does not account for the eccentricities of the SEAK ecosystem. Additionally, it may not be fully equipped to address population declines due to increased predation by sea otters and other depressing factors.

In light of the ecological and economic importance of geoduck clams and the deficiencies of current management, it is necessary to consider new management regimes. Adaptive management is essential to ensure the sustainability of the geoduck clam population, or both the ecosystem and local economy will suffer. In this paper, we describe the ecosystem of the coastal waters of SEAK, provide an overview of geoduck clam biology and the geoduck clam fishery (including mariculture), describe natural and human impacts to the SEAK geoduck clam population, and propose an improved management strategy to address the diverse interests in, and impacts to, the geoduck clam population.

Ecology of Southeast Alaska's Outer Coast

The shoreline of the outer coast of SEAK is a rocky primary coast created by glacial erosional processes (Martin and Williams, 1924). Outer coastal waters, where geoducks are predominantly found, are more saline than inside waters due to their proximity to the open ocean (Wing et al. 2006). Summer surface temperatures reach approximately 5°C to 6°C (Rorick, 2007) above winter temperatures. A seasonal thermocline results from greater insolation and reduced winds during the spring and summer months (Carlson, 1984). Tidal ranges in SEAK are relatively large due to the great distance from the nearest amphidromic point (Garrison, 2005). Rich supplies of terrestrial nutrients and sediments, mixed into the water column by winter storms, support large plankton blooms that typically cloud surface visibility by April or early May (Carlson, 1984).

Mudflats and beaches are an important feature of the shorelines of SEAK, and are divided into five distinct categories: (1) broad and gently-sloping fine-grained sand beaches; (2) wide and steep coarse-grained sand beaches that are generally associated with river or stream mouths; (3) mixed sand and gravel beaches, characterized by a mix of coarse-grained sand, gravel, and occasional shell fragments; (4) exposed tidal flats, which are composed of sand and gravel and are generally associated with lagoons or found at the heads of coastal bays; and (5) sheltered tidal flats, which are characterized by soft or muddy sand, occurring principally at the heads of bays and estuarine wetlands, where they are exposed to low wave activity and moderate tidal currents. Stress from temperature changes causes high interannual variability in biomass. Microalgal species grow in abundance during spring and summer. Detritus formed by these microalgae are the base of the trophic pyramid as food for benthic organisms such as geoduck clams. Given the ample primary productivity present, space is usually the limiting factor in SEAK's soft-bottom ecosystems (ADF&G, 2005).

Geoduck Clam Biology

The range of the geoduck clam extends from the shores of Kodiak Island, Alaska (58° N) to Baja California (34° N) (Harbo,1997); however, harvestable populations do not exist north of SEAK (Hebert pers. comm.). In Alaska, geoduck clams primarily inhabit soft bottoms from low intertidal zones to depths greater than 60 meters, although populations have been observed living as deep as 110 meters (Goodwin and Pease, 1989). Geoduck clams can grow larger than 212 mm (shell length) and 2.35 kg (wet weight) (Vercessi pers. comm.). Adult geoduck clams are characterized by their large siphon, which they use to reach the surface of the substrate to access suspended nutrients (http://www.adfg.alaska.gov/index.cfm?adfg=geoduck.main).

Adults reach full sexual maturity at three to eight years of age, with males typically beginning to spawn at three years and females at four years (Andersen, 1971). Geoduck clams are broadcast spawners, with individual females producing 1-2 million eggs during a spawning cycle. The size of an individual geoduck clam is suspected to relate to the fecundity of the individual; larger geoduck clams produce more gametes, leading to a greater chance of spawning success (RaLonde pers.

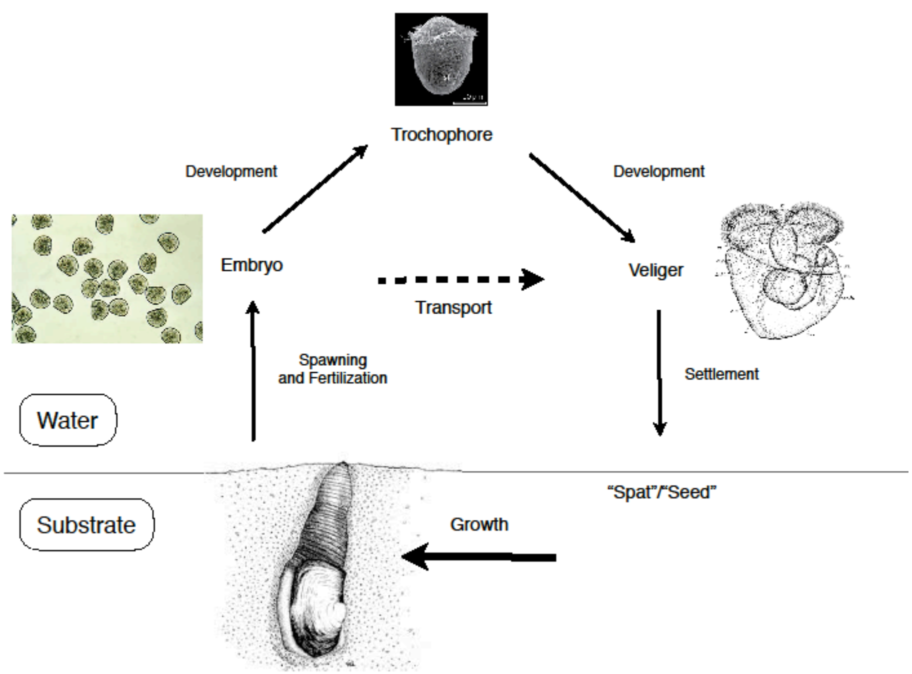

Figure 1. A diagram showing the life cycle of the Pacific Geoduck clam (Goodwin and Pease, 1989). Drawings not to scale.

comm.). Spawning occurs annually from March to July, though the exact conditions optimal for spawning are not well understood (Straus et al. 2009). Geoduck clams are extremely long lived; fossil and shell records indicate that individuals can live for over 150 years (Goodwin and Pease, 1989).

Natural influences on the geoduck clam populations include many factors (Siddon, 2007). Like most other bivalves, geoduck clams exhibit a seven stage lifecycle (Goodwin and Pease, 1989) (Figure 1.). Following fertilization, geoduck clam pronuclei rapidly develop into active planktonic larvae and are especially vulnerable to predation (Straus et al. 2009). The time requirement for larval development is significant. This slow resettlement is due to the large larval drift zones dominating the Alaskan coast that transport larva far from their native beds (RaLonde pers. comm.) During late larval stages, geoduck clams are called veligers, and undergo metamorphosis and settle onto the substrate. Metamorphosis is a critical period in geoduck clam development, and can be impeded by several environmental factors such as water salinity, temperature, and pH (Goodwin and Pease, 1989). A period of rapid development follows metamorphosis, during which juvenile geoduck clams use their foot to dig down into the substrate and feed on detrital matter. During this time, they are susceptible to predation by pelagic and benthic organisms such as sea stars, crabs, and epibenthic fish (Goodwin, 1973). After 2-4 weeks of post larval development juvenile geoduck clams have burrowed deep into the substrate, begin filter feeding (Straus et al. 2009), and become much less susceptible to environmental fluctuations (Goodwin, 1973) and predation (Goodwin and Pease, 1989). Geoduck clams continue growth throughout their adult lives, albeit at a much slower rate, with growth slowing during the winter months (Goodwin and Pease, 1989).

The impact of erratic recruitment levels is buffered by large numbers of mature geoduck clams in a given area (Valero et al. 2004). Current survey methods, which record only the density of mature geoduck clams, do not account for recruitment and mortality and therefore do not provide a complete understanding of the stability and sustainability of geoduck clam populations (RaLonde pers. comm.).

The Geoduck Clam Fishery in Alaska

The earliest commercial harvest of geoduck clams in Alaska began in 1973, but interest remained low until 1977, when divers from Washington arrived in Alaska to investigate the possibility of establishing a commercial geoduck clam fishery (Walker, 2000). The Alaska Department of Fish and Game (ADF&G) allowed the first official geoduck clam harvest in 1983. Alaskan geoduck clam soon gained a reputation for having very high quality meat, causing a rapid rise in its market price (Walker, 2000) (Figure 2.).

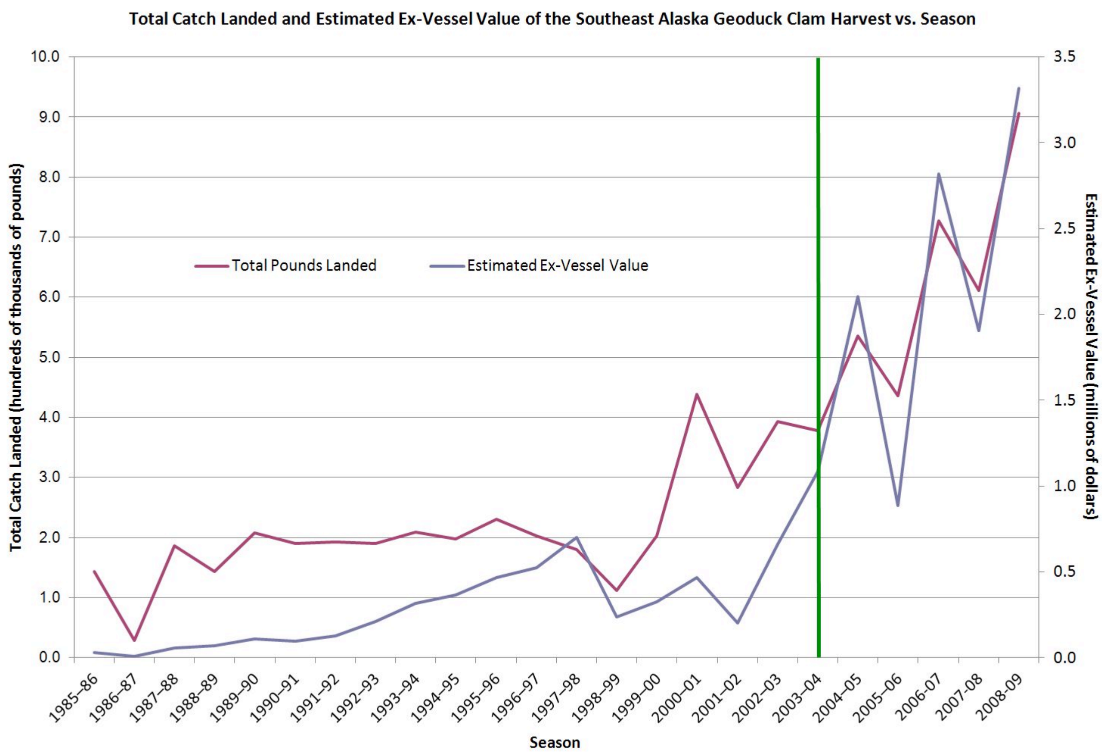

Figure 2. A graph showing the total catch landed (purple) and estimate ex-vessel value (blue) for the SEAK geoduck clam harvest from 1985 to 2009. The year that ADF&G began testing for paralytic shellfish poisoning is indicated with a green vertical line (http://www.adfg.alaska.gov/index.cfm?adfmg=commercialby area southeast.dive_harvest_geoduck).

Initially, after the opening of the SEAK geoduck clam fishery, ADF&G opened several areas for geoduck clam harvest, ranging from Symonds Bay on Biorka Island near Sitka, to Kah Shakes south of Ketchikan, to the west coast of Gravina Island, to the northern shore of Noyes Island west of Craig (Figure 3.).

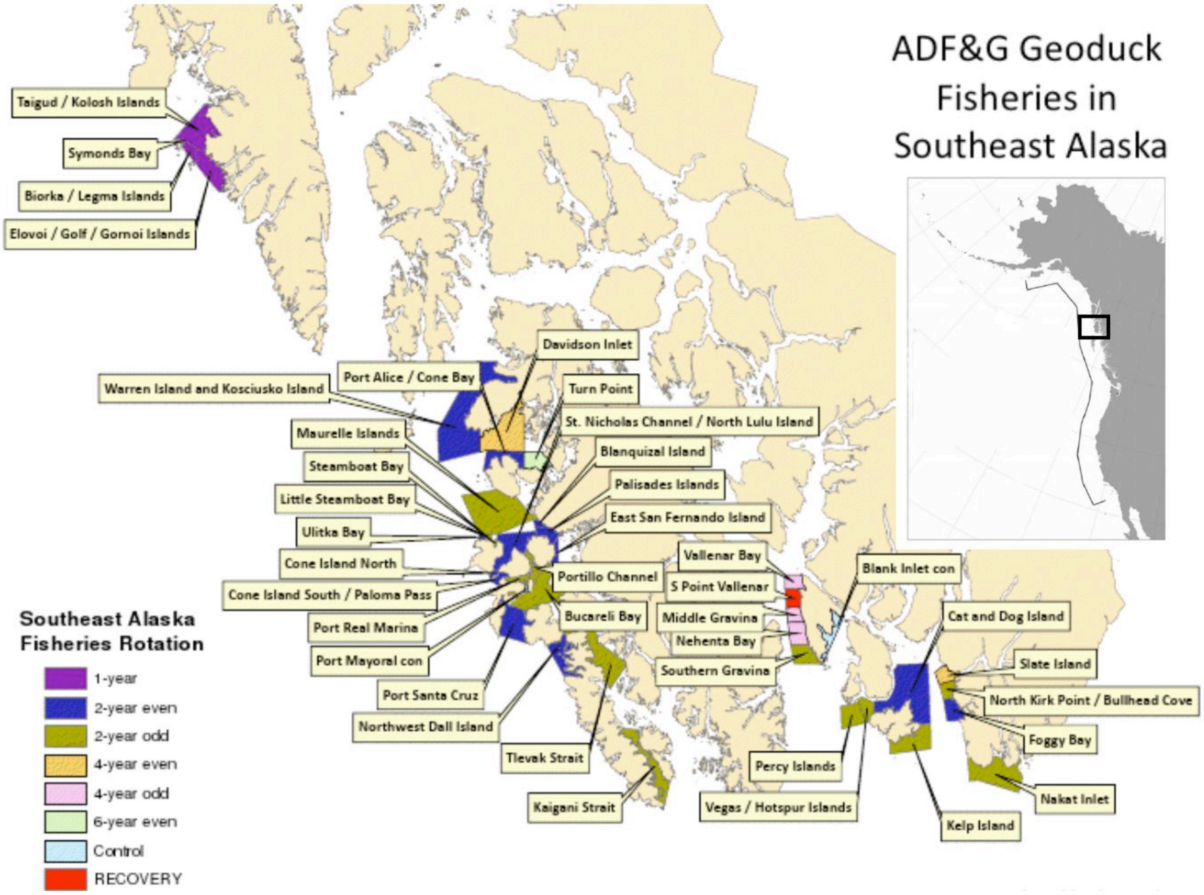

Figure 3. A map showing the location of the various SEAK geoduck clam fishery areas managed by ADF&G. Note that the color code displayed at the bottom left indicates fishery rotations and that each area is labeled with its official name (http://www.adfg.alaska.gov/index.cfm?adfg=CommercialByFisheryDive.geoduck).

By the late 1980's, most divers had replaced hand-digging and SCUBA diving methods with the use of high-powered water jets and boat-mounted breathing apparatuses to allow for more efficient excavation and longer periods of time underwater, increasing harvest rates. In 1998, fishermen formed the SEAK Regional Dive Fisheries Association (SARDFA). SARDFA is responsible for representing the fishery's interests while collaborating with ADF&G to develop an Annual Operating Plan (http://www.sardfa.org). SARDFA imposes a 7% tax on geoduck harvests to fund experimental enhancement efforts and maintain regular paralytic shellfish poisoning (PSP) and water quality testing near geoduck clam beds. ADF&G and the Alaska Department of Environmental Conservation (DEC) collaborate with SARDFA to coordinate management efforts to maximize the success of the geoduck harvest in SEAK (Rumble pers. comm.). Geoduck taxes have also funded SARDFA reconnaissance surveys to identify new geoduck beds. ADF&G has conducted stock assessment surveys in these areas and opened many of them to commercial fishing (Rumble pers. comm.).

Since the implementation of a management plan for the geoduck clam fishery during the 2000-2001 season, the value of the SEAK harvest has increased more than 157% (Figure 2.). This is primarily due to the expansion of the fishery into areas previously not available to commercial harvest (Rumble pers. comm.). Demand for geoducks and changes in PSP testing that allowed for increase in live sales caused the value of live geoducks to increase from $0.70/lb to the current price exceeding $10.00/lb over the last decade (Prichett and Hoyt, 2008) and the ex-vessel value of the total fishery grew to over $4 million (Figure 2.).

A major challenge to the geoduck clam fishery in SEAK is the occurrence of contamination by PSP-causing toxins. In 1988, off the shore of Ketchikan's Gravina Island, PSP tests of geoduck clams revealed the highest levels in SEAK (Walker, 2000). PSP contamination is a serious economic concern for the geoduck clam fishery as it requires the sampling of individuals from every fishery area, costing an average of 5% of the harvest value of all bivalves in Alaska and delaying harvest until results are produced (Botana, 2008). The total cost of PSP contamination to the commercial fishery, recreational harvest, and mariculture of Alaskan shellfish surpasses $10 million each year (RaLonde, 1996). Currently, DEC monitors the geoduck clam population for the presence of PSP, while fishermen pay, through SARDFA, for the transportation of harvest samples to DEC, which tests for and monitors occurrences of PSP contamination.

The threat and outbreak of PSP has a much more profound effect on the geoduck clam fishery than testing costs alone. In the Alaska geoduck clam fisheries, only the visceral mass is tested for PSP because the toxin is not concentrated in meat tissue (Doherty pers. comm.). If PSP is about 80 micrograms in the viscera, the clams must be killed, the visceral mass removed, and frozen. The difference in value between live sale of PSP-free clams and frozen meat is substantial. PSP is a major reason for the reduced value of geoduck clams captured in the Gravina Island fishery (RaLonde pers. comm.).

Geoduck Clam Mariculture in Alaska

Following the success of geoduck clam farming in Washington State and British Columbia, dive fishermen and independent entrepreneurs began to assess the possibility and profitability of intertidal and subtidal mariculture operations in SEAK. The Alaska Legislature enacted statutes for the farming of geoducks in 1988 (seagrant.uaf.edu/map/aquaculture). The regulatory structure of geoduck clam mariculture, outlined in Alaska Regulation and Administrative Code 5 AAC 41.210-400 requires harvesters to obtain permits from both the Alaska Department of Natural Resources and ADF&G. The applicant must also provide a $5000 fee for the ADF&G dive survey team to survey the area of the prospective farm site to insure that there is no more than an "insignificant" (<2000 pounds per acre) geoduck clam population already present (Aquatic Farming, 1988). Commercial dive fishermen were concerned that the subtidal mariculture leases would displace them from the geoduck clam beds, reducing profits. Alaska Trademark Shellfish LLC filed several lawsuits against the State of Alaska regarding ownership of wild geoduck clams on mariculture plots, claiming a breach in common property and public trust laws. Each was decided in favor of the state, and ADF&G followed by imposing new regulations on the industry, exacerbating discontent among the mariculturist community (Alaska Trademark Shellfish LLC et al. v. State of Alaska et al.).

Seed security, the availability of Alaskan geoduck clam spat, is a significant challenge to the geoduck clam mariculture industry in SEAK (Manning pers. comm.). Geoduck spat is produced in the

Alutiiq-Pide Shellfish Hatchery in Seward until individuals reach roughly 4 mm in length and is then sold and shipped to farmers for planting. As it is against Alaska law to import spat from outside the state, the only source of geoduck clam spat is the Seward hatchery. The challenges presented by a single seed supplier prevented many farmers from planting live geoduck clam spat until several years after the opening of the hatchery (Manning pers. comm.; Josephson pers. comm.). A SEAK hatchery in Ketchikan, which is much more central to the farm sites and located in the pristine waters of SEAK, has been proposed in order to mitigate this limitation (RaLonde pers. comm.). Such a hatchery would not only have better access to geoduck clam brood stock, but also bring valuable jobs and capital to the region.

In intertidal areas, a farmer plants cultured geoduck clams by manually distributing spat into pipes, covered with mesh to prevent predation. In subtidal areas, a farmer may anchor predation preventing mesh over the area to be planted, and spread spat manually through the mesh. Some farmers set individual larger spat in a grid, inserting each spat into the substrate (Josephson pers. comm.). It takes from five to ten years for geoduck clams to reach market size in both intertidal and subtidal SEAK farms, making mariculture operations long-term investments (Manning pers. comm.). There are currently 16 subtidal and 5 intertidal permitted farms that focus primarily on geoduck clams (21 total permitted and leased sites) operated by 9 individuals (Vercessi pers. comm.).

Discussion of Possible Impacts to the Geoduck Clam Population

A multitude of diverse factors impact the success or decline of the geoduck clam population, including survivability of larvae under changing salinity, pH, and temperature, the effects of predation (specifically that by sea otters), the potential influence of current geoduck clam harvesting methods on the population and the surrounding ecosystem. We will also discuss the potential impacts of the introduction of hatchery-reared geoduck clams, and the implications of basing harvest level calculations on those used in the management of the WA and BC geoduck clam populations.

The optimal water temperature and salinity for the development of geoduck clam larvae increases as larvae transition from embryonic stages to planktonic larvae (Lough, 1975). Studies on geoduck clam recruitment at a specific site in relation to water temperature, pH, and salinity are difficult; geoduck clams' larval drift zones are large and larva produced in an area of optimal temperature and salinity could drift into an area where the water quality is less favorable at the time of recruitment (Vercessi pers. comm.). While fluctuating water temperatures will have an impact on larval development and dispersion, it is difficult to predict what effect local changes in water properties will have on repopulation (RaLonde pers. comm.), as the larvae produced by a given population have the potential to drift far away from their spawning location settling larvae produced in different locations.

Anthropogenic climate change has been projected to have a direct impact on global water temperature and pH; however, it is very difficult to predict the effects that climactic changes will have on the complex biological systems of Southeast Alaska (Hebert pers. comm.). Geoduck clams' shells are composed of aragonite, a calcium carbonate compound that reacts readily with carbonic acid (Orr, 2009); increases in water acidity have a profound effect on aragonite-shelled organisms (Dickson, 2010). Rising water temperature may result in faster growth rates of geoduck clams, and thus faster turnover after harvests. Both larval development and adult growth is tied to temperature (Straus et al. 2009). Increasing temperature may extend the northern range of geoduck clams into waters that were previously too cold to support a significant biomass (Siddon pers. comm.). A larger area and greater regional biomass could allow fishermen to see significantly larger harvests and increase the value of the fishery to the State of Alaska. An increased growth rate could also bring farmed geoduck clams to marketable size more quickly, enabling farmers to increase profits.

The marine ecosystem of SEAK is complex, and it is possible that an increase in water temperature could also have a negative effect on the geoduck clam populations via its effect on factors other than larval development and growth rates. For example, increased water temperatures may have detrimental effects on other aspects of the ecosystem that influence geoduck clam population, such as food sources and predators. Higher water temperatures have the potential to increase geoduck clam turnover, but the net impact of temperature rise on geoduck clams and the ecosystem around them is difficult to determine (Herbert pers. comm.).

While an expanding mariculture industry in SEAK is economically beneficial, it does pose another potential cause for concern: gene flow between wild and cultured geoduck clams. As the geoduck mariculture industry in SEAK grows, so too does the potential for hatchery-introduced geoduck larvae to enter the ecosystem. Geoduck clams are broadcast spawners and it is impossible to contain the release of offspring. While natural selection would theoretically eliminate any detrimental genetic traits that enter the wild population, the introduction of pathogens and the risk of decreasing local genetic diversity is a cause for concern (Fisher, 2008). However, Alaska managers have sought to address this issue by only spawning adults for one season, requiring a minimum number (50 male and 50 female) to be used each year, and only using SEAK geoduck clam brood stock (Josephson pers. comm.).

Sea otters pose a significant threat to geoduck clam populations because, unlike other predators, they can excavate and consume entire geoduck clams (Reidy, 2011). Large concentrations of otters have been known to completely eradicate local shellfish populations, and therefore pose a significant threat to the geoduck clam population (Siddon pers. comm.). Managers and fishermen alike argue that sea otters represent the single greatest threat to the geoduck populations in SEAK (Doherty pers. comm.).

The primary means of extracting geoduck clams from substrate, using water jet apparatuses, is a potential threat to the geoduck clam fishery and the surrounding ecosystem. The water jet method could upset bioturbation, significantly alter the infaunal community (Wilner, 2006), and increase the likelihood of PSP occurrence; the lifecycle of dinoflagellates *Alexandrium spp.,* which are the producers of the PSP toxin, involves a dormant, sessile phase in which the dinoflagellate settles to form a cyst and remains dormant until optimal conditions for growth are present. Activation can also occur if the cyst is resuspended in the water column. Water jets or the otters' method of extraction may both distribute and activate dinoflagellates (Willner, 2006). Studies have shown, however, that resuspension of PSP-producing algae by dive fishermen's current harvesting method is overshadowed by more influential factors such as water temperature, salinity, and photoperiod (Fisher, 2008). The re-suspension of detritus through excavation by water jets may also potentially provide more nutrients to geoduck clams and other fauna in the ecosystem (Hebert pers. comm.). As with all ecosystem interactions, the impact of current excavation methods has both positive and negative components and must be taken into consideration in any effective management plan. However, there is no alternative methodology that would reduce impacts. Until another method is proposed, the water-jet method remains the most viable option for geoduck harvesting, despite possible negative impacts.

The number of surveys of geoduck clam populations in SEAK is not yet sufficient to make accurate estimates of recruitment and natural mortality, so ADF&G uses population estimate equations partly based on those developed in WA and BC (Hebert pers. comm.). The SEAK geoduck clam fishery GHLs are calculated as 2% of the lower bound of the 90% confidence interval surrounding the population biomass estimate, while estimates used in WA and BC are calculated based on the point estimate of biomass. In addition, small differences in salinity, temperature, and pH between WA, BC, and SEAK make reliance on outside management regimes problematic, as geoduck clam larvae are easily influenced by minute changes in their surroundings (Straus et al. 2009).

Improved Management of Geoduck Clam Fishery and Mariculture

We propose improvements to the existing management plan for SEAK geoduck clams that are intended to achieve the maximum sustainable yield (MSY), exploiting the species for maximum economic gain while ensuring sustainability for the benefit of the ecosystem and future fisheries, as required by the Alaska State Constitution. We propose: (1) additional research into the overall health of the geoduck clam population; (2) further research into the impacts thereupon; (3) development of a state-operated hatchery and nursery; (4) establishment of a PSP contamination testing lab in SEAK and concurrent work toward the development of an FDA-approved field test for PSP; (5) implementation of an enhancement program for the wild geoduck clam population; (6) adjustment of the GHL to reflect the specific needs of SEAK's geoduck clam population; (7) adoption of a new population survey and harvest schedule; (8) development of programs to encourage intertidal farming of geoduck clams; and (9) ongoing research in order to determine the efficacy of our management methods in achieving sustainability.

As with any ecosystem-based approach to management, any attempt to sustainably manage the SEAK geoduck clam population must be accompanied by a significant volume of research. This must include additional research into the "hidden" parameters that most directly reflect the health of the population, including overall recruitment, fecundity, age distribution, and mortality rates, as well as further research into the impacts of sea otter predation, habitat degradation, and harvest methods on the geoduck clam population and the surrounding ecosystem. This research must then be used to support adaptive management strategies to meet the needs of both the fishery and ecosystem in a dynamic environment.

Because research represents a significant expense with little immediate economic benefit to the fishery, we also propose implementing a series of measures to increase the financial success of the commercial geoduck clam harvest while being mindful of the health of the SEAK ecosystem. These measures are discussed below.

The prospective geoduck clam mariculture industry in SEAK is in its infancy; to develop this industry it is essential to ensure secure and rapid access to geoduck clam spat. A principal method of ensuring this access would be to create a shellfish hatchery in, or in closer proximity to, SEAK. This would be a suitable mitigation to the concerns of geoduck clam farmers who suspect the long distance of travel and over-handling of the fragile spat may be the cause of the limited survivability observed by many growers (Manning pers. comm.). The nursery in Ketchikan proposed by OceansAlaska provides the most central and sensible location relative to the geoduck clam mariculture sites (OceansAlaska, 2006). This nursery would be useful not only for the actual development of geoduck clam spat, but also for controlled research purposes.

Rising concern over PSP contamination in the SEAK shellfish population mandates the continuation of current extensive testing procedures. Fishermen within SARDFA must pay a total of $40,000 per year to account for the cost of testing and transportation of samples to the DEC PSP contamination testing facility in Palmer. After receipt of favorable test results, sampled beds must be harvested within three days. The loss of profit and small harvest window could be mitigated by establishing a DEC PSP testing lab closer to the shellfish fisheries of SEAK (Doherty pers. comm.). Additionally we recommend the concurrent development of an FDA-approved portable PSP testing kit, which would provide streamlined, convenient, and inexpensive testing for all users.

Private hatcheries in both WA and BC provide spat to fishery managers, who then enhance wild geoduck clam populations through seeding commercially harvested areas with farmed spat. Such a method is a powerful tool for ensuring the long-term success of the population even as other factors, including predation pressure and climatic conditions, fluctuate over time. This may a viable option for supporting the geoduck clam population of SEAK in the face of growing predation pressure from sea otters. This option would likely be welcomed by fishermen and managers alike, as it increases the potential value of the dive fishery and supports a species that is integral to the ecosystems of the inside waters of SEAK.

Currently, ADF&G aims to conduct stock assessment surveys every 6 years with a maximum of 12 years between surveys. Most fishery areas are open every other year but some have longer rotations (Rumble pers. comm.). The health of geoduck populations can vary wildly over a short span of time due to climatic and biotic change in SEAK. Yearly surveys of the fishery areas within the region would benefit both the species and the fishermen, providing a more extensive data bank on population trends, providing managers with more precise estimates that could enable them to set higher (though still sustainable) GHLs.

Key industry stakeholders have suggested that the GHL established by ADF&G varies too greatly from one year to the next, as harvest rotation is not intended to provide consistent harvest levels, but only to meet the ecological needs of the various areas (Doherty pers. comm.). We recommend that rotations of the various harvest areas be realigned in order to achieve a relatively consistent GHL, while maintaining current harvest rates for each individual site.

A possible solution to the competition between farmers and dive fisherman is the elimination of subtidal farming, shifting instead to intertidal farms. Wild geoduck clams do not occur naturally in intertidal areas, but can grow there if seeded. Dr. Raymond RaLonde, an aquaculture specialist with the University of Alaska Fairbanks Sea Grant Marine Advisory Program recently completed an intertidal study on geoduck clam growth rates. This study indicates that farmed intertidal geoduck clams have a high (68%) survival rate, but slow growth rates. RaLonde also found that geoduck clams might take as much as ten years to reach market size, rather than seven (RaLonde pers. comm.). Because of this slower growth rate, we propose that the intertidal mariculture leases be renewed every fifteen years rather than the ten year leases that are currently in place (Vercessi pers. comm.). This change would encourage investment in intertidal geoduck clam farming and reduce competition between fishermen and mariculturists (RaLonde pers. comm.).

Predation by sea otters is a principal concern of industry stakeholders (Doherty pers. comm.) and a management strategy with the goal of limiting sea otters' effects on the ecosystem, either by reducing their population or confining them to certain areas, should be pursued if the shellfish fisheries of SEAK are to be maintained and enhanced. The sea otter population is growing rapidly, and otters have been known to devastate prey species over broad expanses (Siddon pers. comm.; Doherty pers. comm.). There have been significant effects from sea otters in some geoduck fishery areas resulting in diminished GHLs (Rumble pers. comm.). However, as sea otters are covered under the Marine Mammal Protection Act (MMPA), management of the species is problematic. Relocation or containment programs that do not harm the otters would be expensive and time-consuming, and a management plan that incorporates euthanasia would be ethically questionable, unpopular with the public, and illegal under the MMPA. Thus, while we acknowledge the need for a plan that addresses predation by sea otters on SEAK shellfish, a specific plan to do so would be extremely complex and is therefore beyond the scope of this paper. Tamone et al. (2011) present a good introduction to and discussion of the impact of sea otters in SEAK. A compensation program implemented by the Federal government for losses in the fishery due to sea otter predation offers a potential short-term solution. This would allow the geoduck clam fishermen to stay operational, but does not address the threat sea otters pose to the geoduck clam population.

Conclusion

The geoduck clam population in SEAK is important both to the economies of SEAK communities and the ecosystems of the region. A growing demand from Asian markets ensures that this fishery, if managed sustainably, will remain valuable long into the future. A surging sea otter population presents significant management difficulties, however, and prompts some industry stakeholders to argue that harvest levels in areas heavily impacted by sea otters should be set at higher levels to maximize yield before the geoduck clam populations are eliminated; however, this stance does not conform to constitutional requirements for sustainable management of natural resources. Current management regimes should be improved to successfully and sustainably manage the harvest of the geoduck clam population with the ultimate goal of attaining the MSY, taking into account the many ecological and physical pressures on the species. Such management requires a significant volume of new research specifically tailored to the needs of the SEAK ecosystem. We recommend a thorough investigatory approach similar to that contained in our management plan. We recognize that ours is not the only approach to management; however, our recommendations contain elements that will be necessary for the success of any management solution: ongoing and expanded surveys to determine the health of the geoduck population, comprehensive research into the pressures acting upon the population, and continued active involvement of industry stakeholders. Regardless of the management solution chosen, new methods must be pursued, as the existing management strategy is poorly equipped to maximize the socioeconomic benefit of the geoduck industry and address the dynamic needs of the SEAK ecosystem.

Works Cited

ADF&G (Alaska Department of Fish and Game). 2005. Featured Species-associated Intertidal Habitats: Rocky Intertidal, Mudflats and Beaches, and Eelgrass Beds. Appendix 5.4 Marine and Coastline Habitats. 25 pages.

ADF&G; to inform the public about the geoduck clam. http://www.adfg.alaska.gov/index.cfm?adfg=geoduck.main. 10/2/11.

ADF&G; to inform the public about the geoduck dive fishery. http://www.adfg.alaska.gov/index.cfm?adfg=CommercialByFisheryDive.geoduck. 11/11/11.

ADF&G; to inform the public of historic geoduck harvest values: http://www.adfg.alaska.gov/index.cfm?adfmg=commercialbyareasoutheast.dive_harvest_geoduck. 11/11/11.

ADF&G; to inform the public of the growing aquaculture industry. http://www.adfg.alaska.gov/index.cfm?adfg=wildlifenews.view_article&articles_id=169&issue_id=31. 11/13/11.

Alaska Trademark Shellfish LLC et al. v. State of Alaska et al., AS 16.40.100-.199. (Supreme Court of the State of Alaska, 2004).

Andersen, A. 1971.Spawning, growth and spatial distribution of the geoduck clam, *Panopea generosa* (Gould) in Hood Canal. Thesis (Ph. D.)--University of Washington.132 pages.

Aquatic Farming, AK Admin. Code. 5AAC 41.210-400 (1988).

Botana, L.M. 2008. Seafood and Fresh Water Toxins: Pharmacology, Physiology, and Detection. Florida: CRC Press. 943 pages.

Carlson, H.R. 1984. Seasonal distribution and environment of adult Pacific herring (*Clupea harengus pallasi*) near Auke Bay, Lynn Canal, Southeastern Alaska. Oregon State University. 45 pages.

Dickson, A. 2010. Ocean Acidification Impacts on Shellfish Workshop: Findings and Recommendations. University of California San Diego. 36 pages.

Doherty, Phil. Southeast Alaska Regional Dive Fisheries Association, PO Box 5417, Ketchikan, AK 99901, (907) 225-2853.

Fisher, J., M. Meaders, S. Luchessa, K. Mueller. 2008. A Supplemental Analysis of the Environmental Concerns Associated with Intertidal Geoduck Clam Aquaculture: Effects on Wild Geoduck Genetics, Potential for Toxin Resuspension , and Effects on Soft-Sediment Associated Communities. Environ International Corporation. 41 pages.

Garrison, T. 2005. Oceanography: An Invitation to Marine Science, Sixth Edition. Thompson Brooks/Cole. 588 pages.

Goodwin, C.L. 1973. Effects of salinity and temperature on embryos of the geoduck clam (*Panopea generosa* Gould). Proceedings of the National Shellfisheries Association 63: 93-95.

Goodwin, C.L., and B. Pease. 1989. Species profiles: life histories and environmental requirements of coastal fishes and invertebrates (Pacific Northwest)--Pacific geoduck clam. U.S. Fish. Wildl. Serv. Biol. Rep. 82(11.120). U.S. Army Corps of Engineers, TR EL82-4. 14 pages.

Harbo, R. 1997. Shells and Shellfish of the Pacific Northwest. Maderia Park, BC: Harbour Publishing. 272 pages.

Hebert, Kyle. ADF&G, PO Box 110024, Douglas, AK 99824, (907) 465-4228.

Josephson, Ron. ADF&G, PO Box 115526, Juneau, AK 99811, (907) 465-4088.

Lough, G. 1975. A Reevaluation of the Combined Effects of Temperature and Salinity on Survival and Growth of Bivalve Larvae Using Response Surface Techniques. Oregon State University. Pages 86-94.

Manning, Thomas. Krestof Clam Company, 622 Hemlock Way, Juneau, AK 99801, (907) 523-1547.

Martin, L. and F.E. Williams. 1924. An Ice-Eroded Fiord: The Mode of Origin of Lynn Canal, Alaska. *Geographical Review* 14: 576-596.

OceansAlaska. 2006. Tipping the Balance: Bringing Alaska's Shellfish Industry to the Takeoff Point. 67 pages.

Pritchett, M. and Z. Hoyt. 2008. Report to the Board of Fisheries, Miscellaneous Dive Fisheries. Alaska Department of Fish and Game, Fishery Management Report No. 08-63, Anchorage.

Reidy, R. 2011. The Potential Impact of Sea Otters (*Enhydra lutris*) on the British Columbia Geoduck Clam (*Panopea abrupta*) Fishery. Simon Fraser University, School of Resource and Environmental Management. 118 pages.

RaLonde, R. 1996. Paralytic Shellfish Poisoning: The Alaska Problem, Vol. 8(2). University of Alaska Sea Grant, Fairbanks, AK. 20 pages.

RaLonde, Raymond. UAF, 1007 W 3rd Avenue #100, Anchorage, AK 99501, (907) 274-9697.

Rorick, M. 2007. Petition to list the Lynn Canal distinct population segment of Pacific Herring (*Clupea pallasi*) under the Endangered Species Act. Juneau Group of the Sierra Club. 71 pages.

Rumble, Janet. ADF&G, PO Box 110024, Douglas, AK 99824, (907) 465-4200.

SARDFA (Southeast Alaska Regional Dive Fisheries Association); to inform the public of SARDFA's mission and practices. http://sardfa.org. 11/17/11.

Siddon, C. 2007. Evaluation of the Southeastern Alaska Geoduck (*Panopea generosa*) Stock Assesment Methodologies. ADF&G Special Publication No. 07-02. 14 pages.

Siddon, Christopher. ADF&G, PO Box 110024, Douglas, AK 99824, (907) 465-4226.

Straus, K., L. Crosson, B. Vadopalas. 2009. Effects of Geoduck Aquaculture on the Environment: A Synthesis of Current Knowledge. School of Aquatic and Fishery Sciences, University of Washington. 64 pages.

Tamone, B., E. Roemeling, T. Monkman, J. Connally, K. Cummins. 2011. The Effects of sea otter (*Enhydra lutris)* reintroduction in Southeast Alaska on the dive fisheries of southern southeast Alaska. 20 Pages.

Vadopalas, B., D. Armstrong, C. Friedman, K. Feldman, G. Van Blaricom, D. Cheney, J. Davis, R. Elston, A. Suhrbier. 2005. Identification of Research Priorities Relevant to Geoduck (*Panopea abrupta*) Aquaculture Environmental Impacts. Prepared for the Washington State Department of Natural Resources. 32 pages.

Valero, J., C. Hand, J. Orensanz, A. Parma, D. Armstrong, R. Hilborn. 2004. Geoduck (*Panopea abrupta*) Recruitment in the Pacific Northwest: Long-Term Changes in Relation to Climate. Pages 80-86.

Vercessi, Lorraine. ADF&G, PO Box 115526, Juneau, AK 99811, (907) 465-6423.

Walker, S. 2000. a Historical Overview of the Geoduck Fishery in Southeast Alaska, 1973-1997.Alaska Department of Fish and Game division of Commercial Fisheries. 41 pages.

Willner, G. 2006. The Potential Impacts of the Commercial Geoduck (*Panopea generosa*) Hydraulic Harvest Method on Organisms in the Sediment and at the Water-Sediment Interface in Puget Sound. Evergreen State College. 76 pages.

Wing, B. L, M. M. Masuda, and S. G. Taylor. 2006. Time series analyses of physical environmental data records from Auke Bay, Alaska. 75 pages.