Restoration of Razor Clam (*Siliqua patula*) Populations In Southeastern Prince William Sound, Alaska: Integrating Science, Management & Traditional Knowledge in the Development of a Restoration Strategy

Final Report to:

Partners for Fish Wildlife Coastal Program
Alaska Regional Office, U.S. Fish and Wildlife Service

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INTRODUCTION

Historically shellfish resources have played an important role in the ecological and economic sustainability of coastal Alaskan waters. From 1916 until the late 1950's the City of Cordova supported a large commercial razor clam (*Siliqua patula*) fishery and claimed it was the "razor clam capital of the world". Annual commercial harvest included as much as 3.5 million pounds (Fig 1). Beginning in the early 1950's, less expensive Atlantic clams began outcompeting demand for Pacific canned razor clams (Nickerson 1975). Concurrently, commercial production for razor clams shifted to supplying the Dungeness crab (*Cancer magister*) bait market (Trowbridge 1995).

By the early 1960's, Cordova's razor clam fishery had begun to decline due to low population levels presumably as a result of a 1958 dieoff (Nickerson 1975) coupled with overexploitation. The 1964 earthquake caused significant uplift in the Copper River Delta and Prince William Sound. Prime razor clam habitat in Orca Inlet was uplifted 1.6-2 m, and tsunamis and seiches eroded at least 76 cm of surface sediment over large portions of the tidal flats (Reimnitz 1966 cited in Nickerson 1975). A 1965 study by Baxter (1971) concluded that that razor clams around Cordova had experienced moderate mortality as a result of the earthquake, and Nickerson (1975) did locate several clams during his 1969-1975 study that recruited prior to 1964. Nevertheless, low clam harvests around Orca Inlet caused a shift by diggers to the east side of the Copper River Delta around Softuk and areas just west of Controller Bay. From 1983-1988 the majority of the commercial razor clam harvest was taken at Kanak Island, an island located approximately 65 miles from Cordova (Fig. 2). Except for 1993, there has been no commercial razor clam harvest since 1988 (Trowbridge 1995; Fig. 1).

The decline in razor clams around Cordova has posed problems not only for the commercial clam fishery, but also for the coastal ecosystem. Newly recruited razor clams, are an important prey resource for crabs (e.g. juvenile and adult Dungeness crabs; O'Clair and O'Clair 1998), some species of flatfish and birds (gulls, crows, sea ducks, and shorebirds; Tegelberg and Magoon 1969; Lassuy and Simons 1989) while adult razor clams are consumed by sea otters (Kvitek and Oliver 1988).

We hypothesized that through a combination of over-exploitation and natural changes (including tectonic events), a period of low recruitment was experienced in the 1970's and early 80's. These events were of sufficient duration to create a significant reduction in spawning potential of adult stocks that has led to a decrease in natural recruits (i.e. a recruitment bottleneck). The net result is a population that cannot seed itself throughout its geographic potential.

Both coastal Alaska commercial and subsistence fisheries could be significantly enhanced by restoration of a viable shellfish resource. Researchers in several states along the Eastern (NY, VA, NC, and SC) and Western (WA and CA) U.S. coasts have also recognized the ecological and economic necessity for shellfish restoration and enhancement and have adopted approaches that include adult transplants and seeding areas (e.g. Peterson et al. 1995, 1996).

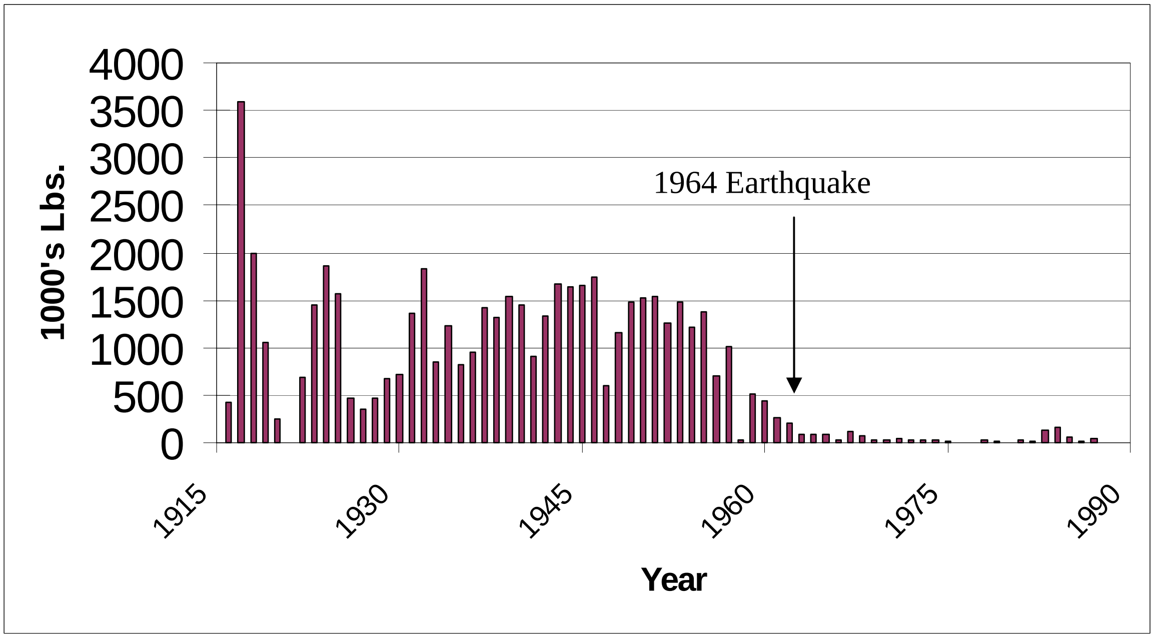

Fig. 1. Razor clam commercial catch on and around the Copper River Delta, 1916-1988. Commercial catch 1983-1988 from Kanak Island and Softuk area only.

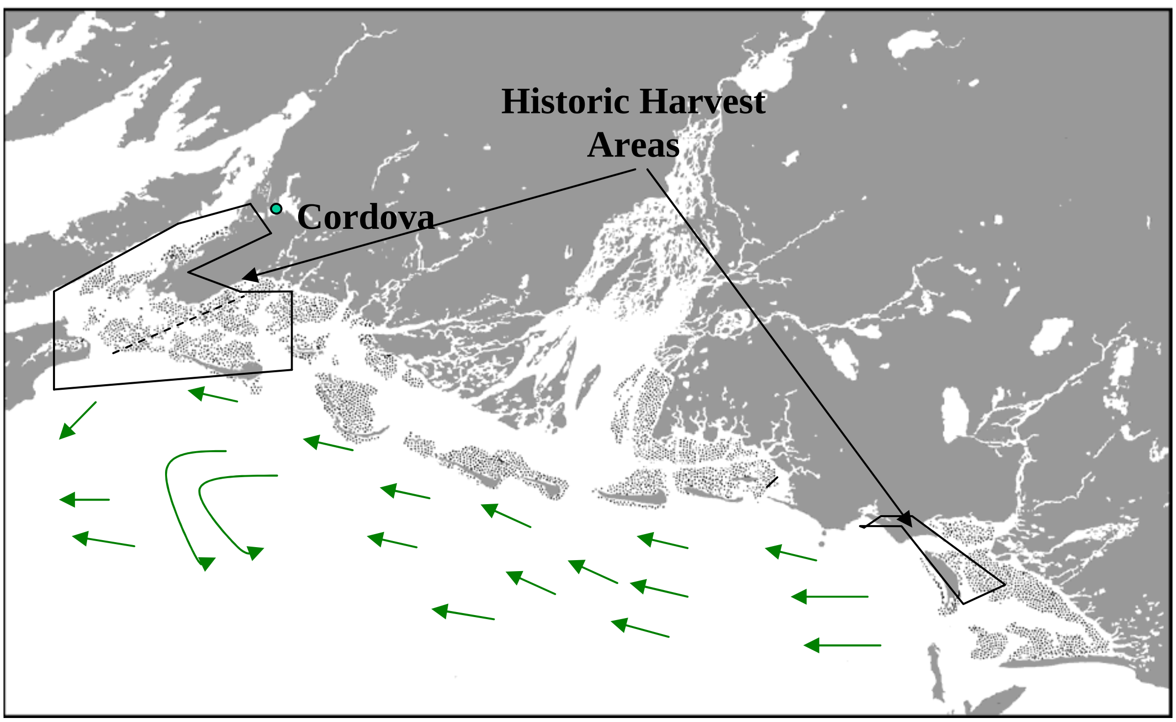

Fig. 2. Locations of historic razor clam harvest areas on and around the Copper River Delta, 1916-1988. Short arrows denote direction of surface currents. Area east of dashed line = permit currently required to harvest razor clams.

For this project, therefore, our efforts have focused on mechanisms for razor clam enhancement in the sandy, high salinity areas of the Copper River Delta. We sampled four historic sites to determine their viability as donor sources for adult razor clams. We initiated small-scale experimental plantings of adult razor clams at selected historic sites currently without razor clams to determine if that habitat is of sufficient quality (in terms of razor clam growth and survivorship) for a shellfish population to become re-established. Based on our results and an examination of other razor clam fisheries, we provide recommendations for razor clam restoration on the Copper River Delta.

METHODS

Traditional Knowledge

We interviewed 4 fishermen between 10-13 September 2001. These included:

1. Bud Janson Sr. Commercial clammer from the 1940's through the early 1960's in lower Orca Inlet. Bud Sr. discussed the history of clamming in Cordova area.
2. Bud Janson Jr. Commercial clammer in the 1960's and recreational clammer since then. Bud Jr. has conducted a systematic search for remaining razor clam beds from lower Orca Inlet (around Mummy Island) to Shipyard Bay.
3. Andrew Smallwood. Pilot who conducted paralytic shellfish poison (PSP) surveys of razor clam beds from Egg Island to Kanak Island in the late 1970's to early 1980's.
4. Brian King. Son of commercial clammers that clammed at Mummy Island. King identified historic areas his father clammed and more recent areas he clammed in Orca inlet.

Clam Densities & Population Structure

Based on our interviews and logistic considerations, we sampled six areas on and around the western Copper River Delta including 4 known to have supported high razor clam densities in the past, and 2 sites suspected to support razor clam densities. Surveys were conducted on the sandier, lower intertidal areas during during minus tides. In September 2001, we surveyed near the outflow at Pete Dahl Channel, southeast of the mouth of the Eyak River, and at Hartney Bay (Orca Inlet). On 27 and 28 April 2002 we surveyed the Rocky Quarry (aka North Concrete Bar) and Bud's Bar, respectively. We surveyed Pt. Steele Beach at Hinchinbrook Island on 12 July 2002.

At 3 sites (Rock Quarry, Bud's Bar, and Pt. Steele Beach), surveys were conducted using methods devised by Nickerson (1975). Depending on the area typically a 3 m x 30 m plot was placed at two mid-tide plots (1.0' above MLLW) and two low (0 to 0.25' below MLLW) tide plots with the long axis of the plot oriented parallel to the water line. All razor clams that showed (i.e. siphon holes are evident on the surface) were dug up with the aid of a clam shovel, and then measured (mm), and aged (using external annuli; Weymouth et al. 1925) while at the site. Typically young clams ($\leq$1.5 yr) do not produce noticeable shows, therefore we effectively only sampled clams $\geq$2.5 years. For comparative purposes, we followed the same protocol for assigning age as Nickerson

(1975), using the external annuli, and subtracting 0.5 years. A subset of the sampled razor clams were retained for transplant experiments.

We sampled 100 m^2 plots previously established as part of a separate study (see Powers et al. 2001) at Hartney Bay (*n*=2 plots), Eyak (*n*=3 plots) and Pete Dahl (*n*=3 plots). Once at the plot, we collected three large samples (each sample consisting of two 15-cm diameter cores) by inserting the core to a depth of 10 cm at haphazardly selected locations within each 100-m^2 plot. The contents of the large samples were then placed in a pre-labeled, plastic bag. Within 12 h the contents of each bag were washed with gentle water pressure onto a 1.0-mm sieve. These samples were then washed onto a 0.5-mm sieve within 12 h. The contents of all remaining material on either size sieve were preserved in 10% buffered formalin. After one week, the formalin was removed and replaced with a solution of 70% ethanol/rose Bengal. All animals in the samples were identified to the lowest practical taxon (usually species or genus) and enumerated under 10x magnification.

Transplant Experiments

Benthic core results at Hartney Bay, a historic razor clam area, yielded no razor clams during the September 2001 sample. Similarly, three previous sampling efforts conducted during 2000 (as part of a separate study) had also yielded no razor clams (Powers and Bishop, unpubl. data). We visited sites around Hartney Bay in February 2002 to investigate the feasibility of experimental plantings in this area. Sediment samples indicated that the substrate is sandy enough to support razor clams.

We took a subsample of razor clams for transplanting from our surveys of two sites in Orca Inlet: Grassy Isle and the Rock Quarry. Clams were individually number-marked with red oil-based paint to identify each clam for growth analysis as well as to assist in clam recovery. Experimental plantings were conducted on 28 April 2002 in Orca Inlet at two sites at Hartney Bay. At each site six, 2 m^2 plots were established, including three plots with netting (to exclude predators), and three control plots without netting (Fig. 3).

For each of the six plots at Site 1, 6 adults clams (78-130 mm length) and 3-6 juvenile clams (30-60 mm length) were planted. For each of the six plots at Site 2, 6 adult clams were planted. Plots were checked approximately every 2-3 weeks following the transplant. On 10-11 July we recovered clams from three plots at each site, and on 7 September we recovered clams from the remaining plots. Excluding clams that died in plots within the first 6 days due to stress, we determined survivorship and growth for transplanted clams.

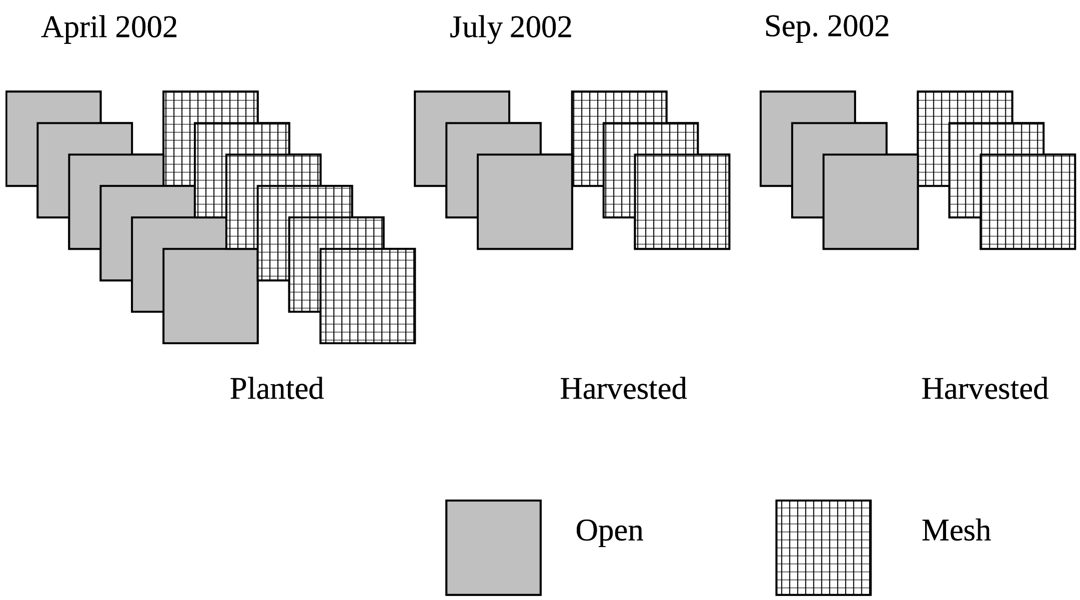

Figure 3. Schedule and sampling scheme for razor clams (*Siliqua patula*) transplanted at Hartney Bay, Orca Inlet, 2002.

RESULTS & DISCUSSION

Clam Densities

At 3 sites: Hartney Bay, Pete Dahl, and Eyak, we found no razor clams, adults or juveniles, in benthic core samples nor were any siphons observed during extensive sampling associated with a concurrent study (Table 1). We speculate that at Pete Dahl and Eyak razor clams are not found because of the high amounts of silt and clay fractions in the sediment (Table 2). Further, the high turbidity of the of the water column, a result of discharge from the Copper River, limits the ability of suspension feeding bivalves like razor clams.

Hartney Bay, our third site without clams, supported razor clam populations as recently as the 1970's. The Alaska Fish and Game 1969-1974 razor clam study (Nickerson 1975) did not report densities for this area. However, Nickerson did collect 178 clams ranging in age from 0.5-6.5 years to determine growth rates for Hartney Bay, indicating that they were abundant (Nickerson p. 234). Sediments in many parts of the area may be unacceptable for razor clams (high silts and clays); however, areas within the Hartney Bay region do have suitable sediments. We speculate that razor clams in areas with suitable sediment are probably limited by arrival of recruits, related to a general lack of spawning stock in the region.

Surveys of the other 3 historic razor clam areas (Rock Quarry, Buds Bar, and Pt. Steele Beach) revealed low densities (Table 1). At Pt. Steele Beach, a historic area of high razor clam densities, when we compared our July 2002 results with surveys conducted by Nickerson (1975), densities of clams are 50 to 70 % lower (after adjusting for slight differences in collection procedures). Based on our discussions with former commercial and recreational diggers, clam densities at the Rock Quarry and at Bud's Bar represented approximately 5-10% of pre-1970 densities. Expressing both our estimates and those of Nickerson's in terms of CPUE (Catch per unit effort) would probably confirm the fisherman's estimates.

Table 1. Razor clam densities by location. Fall 2001-July 2002.

	Plots *N*	Total Area Fished (m^2)	$\bar{x}$ Clams/m^2 $\pm$ SD[1]	Range
Orca Inlet				
Rock Quarry	6	265	0.41 $\pm$ 0.40	0.10 – 1.14
Bud's Bar	4	600	0.03 $\pm$ 0.01	0.02 – 0.04
Hartney Bay	4	300	0	-
Hinchinbrook Island				
Pt. Steele	4	750	0.62 $\pm$ 0.12	0.51 – 0.76
W. Copper River Delta				
Eyak	3	12	0	
Pete Dahl	3	12	0	

[1] $\bar{x}$ Clams/m^2 = adjusted density and assumes on a sunny day 35% of clams show, based on our transplant experiments.

Sediments

Substrates at all three Orca Inlet sites contained relatively high percentages of silt and clay for razor clam beds. In contrast, during Nickerson's study, sediments were 99-100% fine sand at his 7 sites in southern Orca Inlet. Substrate at the Rock Quarry was 100% sand during Nickerson's study, but only 90% during our 2002 study. At Pt. Steele Beach substrate was still similar: Nickerson described the substrate as 100% sand, whereas we found 99% sand during 2002.

Table 2. Sediment composition by site.

Site	% Sand	% Silt & Clay	%Shell material
Hartney Bay	91	8	<1
Rock Quarry	90	6	4
Bud's Bar	90	6	4
Pt. Steele Beach	99	<1	<1
Eyak	83	8	9
Pete Dahl	52	23	20

Population Structure

By survey site, average age of razor clams ranged from 3.3 - 5.4 yr (Fig 4). During the 1950's when the razor clam fishery was still active, annual average age of clams were 7-9 yr (Fig. 5), whereas we found an average age of <5 yrs. These estimates exclude juveniles 1 to 2 yr olds which would not have been collected in the fishery. Nickerson (1975) found that age at sexual maturity varied in Orca Inlet (Table 3), and was best predicted by valve length. He determined that for Orca Inlet area, 99% of the clams >114 mm (4.5 inches), were sexually mature, and that usually clams this size had an average age of 5.5 yr. At Pt. Steele and the Rock Quarry, very few (<1-6%) of the clams were >114 mm (Table 4). While Bud's Bar had low population densities, clams there tended to be mature. Situated west of Orca Cannery, this bed is north of historic razor clam habitat. According to Bud Janson, Jr., his grandfather originally planted razor clams there to provide a winter source of clams. Sandy habitat is limited on this bar, and as a result, this clam bed is relatively small. Currently, this site appears to receive little recreational use.

Compared to Buds Bar, the other two sites with clams are fished by recreational clammers. The Rock Quarry appears to be a favorite clamming area for local Cordovans: the morning we surveyed this bed, we observed at least three other clamming parties. This fishing pressure may explain why the overall age structure of the razor clam population at the Rock Quarry was substantially lower than during Nickerson's study (1975; Fig. 4). At Pt. Steele, recent development of second homes at nearby Boswell Bay has been accompanied by an increase in recreational clamming activities.

Table 3. Percent of maturing individuals by age class in Orca Inlet (Nickerson 1975, p. 47).

Age	% Sexually Mature
2.5	18
3.5	65
4.5	90
5.5	99
6.5	100

Table 4. Average razor clam age by area, and % by size class.

Site	N	$\bar{x}$ age(yr) [1]	$\geq$ 102 mm [3] (%)	$\geq$ 114mm [3] (%)
Pt. Steele	157	3.3	4	<1
Rock Quarry	163	3.6	33	6
Buds Bar	28	5.4	82	57

[1] average age based on clams collected $\geq$ 2.5yrs+; [2]clams >102 mm (4"), 78% are mature; [3]clams $\geq$ 114 mm are 99% mature (Nickerson 1975)

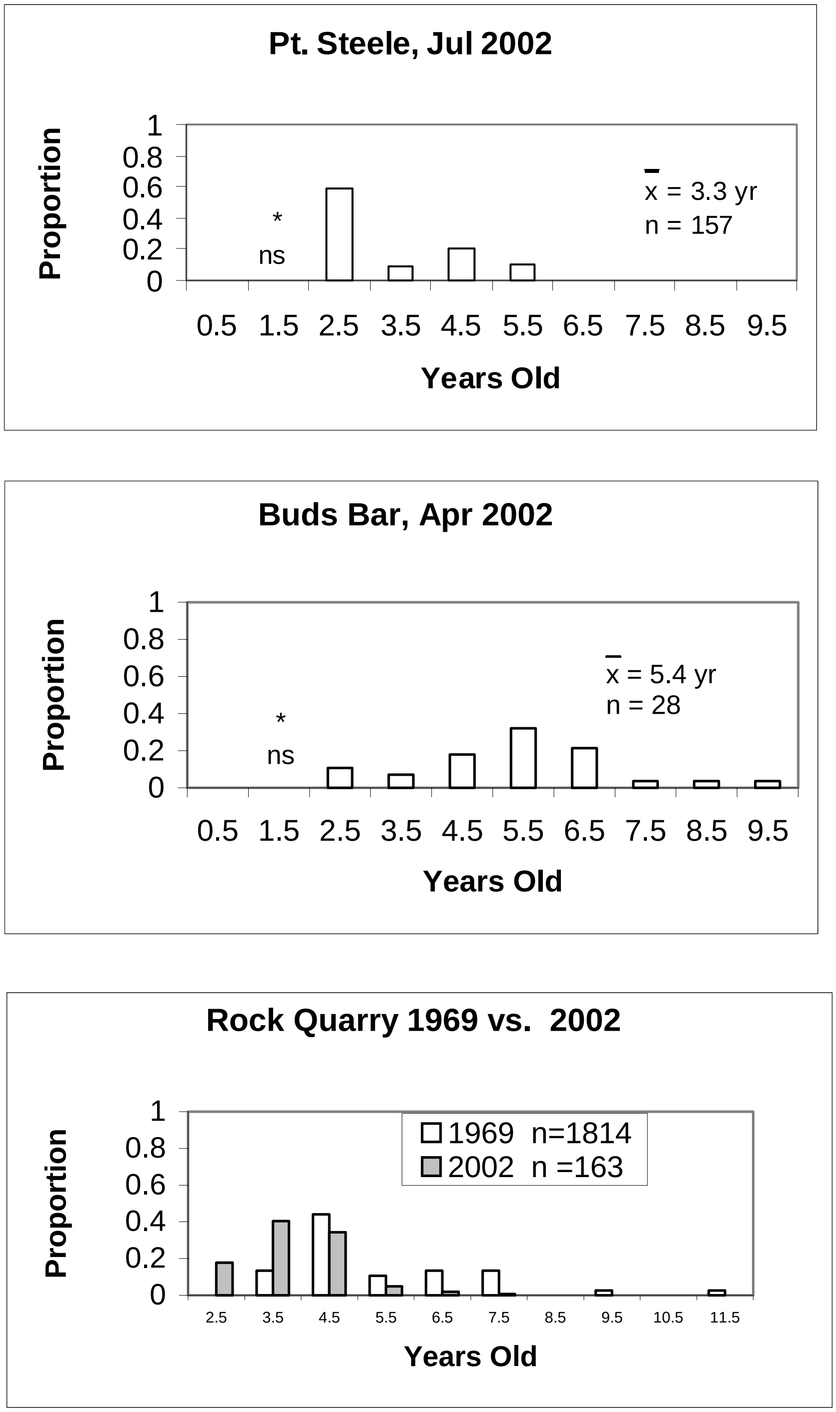

Fig. 4. Proportion of razor clams by age class. Rock Quarry 1969 data from Nickerson (1975, pg. 278).

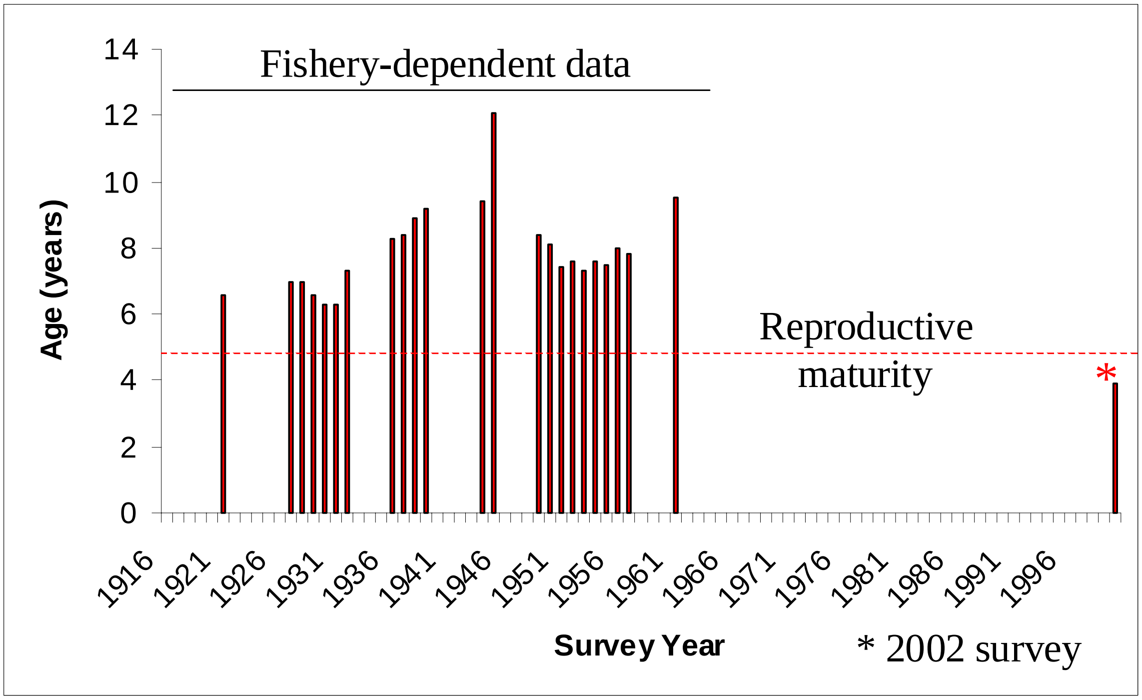

Figure 5. Average age of razor clams harvested in the Cordova area. Historical data from Nickerson (1975).

Transplant Experiments

We transplanted into 12 plots a total of 106 razor clams, including 72 adults and 34 juveniles. Six clams (4 adults and 2 juveniles) died within 6 days of the transplants, apparently from the stress of transplants. Survivorship for both adults and juveniles was highest among clams harvested 10 –11 July (2.5 months post-transplant) compared with clams harvested in 7 September (4.5 months post-transplant) (Fig. 6). Among clams harvested in July, there was no statistical difference in survivorship by age or treatment. Among clams harvested in September, adult clams under mesh showed significantly higher survivorship than adults in non-meshed covered plots (unpaired, two-tailed *t*-test $p < 0.05$ for adult comparisons). Whereas no significant difference between juveniles exposed and under-mesh were detected (unpaired, two-tailed *t*-test $p > 0.05$), a trend of increasing juvenile survivorship was seen (Fig. 6).

Average growth rates of 0.4 mm/month were recorded for clams collected in July. Slightly higher rates were found for clams harvested in September (0.8 mm/month). Evidence (significant weight reduction) of adult razor clams spawning was seen in 3 clams recovered in September.

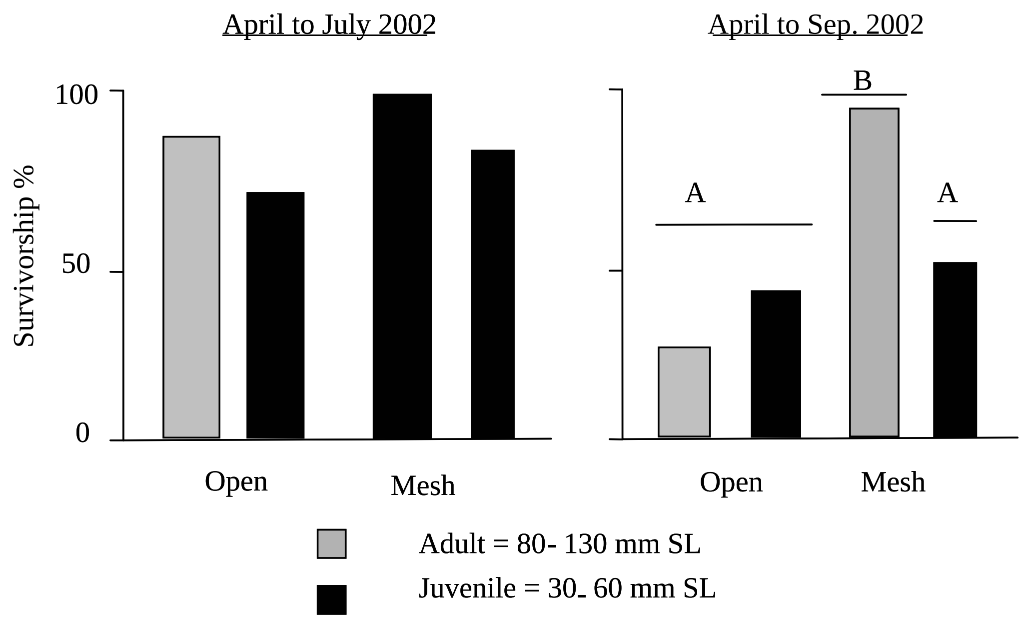

Fig. 6. Results of razor clam transplant experiment by age class and recovery date. Statistical difference detected in adult survivorship for September harvest, unpaired two-tailed *t*-test $p < 0.05$. Hartney Bay area, Orca Inlet, 2002.

RESTORATION OPTIONS

Based on our review of historical landings, previous biological studies, relevant biological information and our recent surveys and fishermen interviews, we believe current populations of razor clam in the Cordova area are limited by an inadequate level of spawning stock. This low spawning stock potential has resulted from the small number of older, reproductively viable clams and has led to a low level of recruitment throughout the Copper River Delta (including Orca Inlet and Pt. Steele Beach on Hinchinbrook Island).

There are many possible causes for the reduction in spawning stock potential of razor clams including: (1) overharvest (historic & current, (2) habitat modification (1964 Good Friday Earthquake, (3) Climate shifts (North Pacific Oscillation), (4) Changes in predator abundances (sea otters & seagulls) and/or (5) Disease.

Of these causes, overharvesting has been a documented, repeated problem in the Cordova razor clam fishery (Weymouth et al. 1925, Nickerson 1975). Whereas disease (primarily NIX, Lindsay and Simmons, 1997) and climate shifts may contribute to the decline in fisheries, the fact that the Cook Inlet populations have not decreased leads us to believe neither of these mechanisms are responsible for the decrease. While habitat modification resulting from the 1964 Good Friday earthquake occurred, our surveys indicate sufficient habitat is available in the area and thus is probably not limiting successful recruitment.

Recruitment limitation resulting from overharvest is emerging as the chief mechanism responsible for the decline of several molluscan fisheries (see Peterson 2002). Fortunately, several restoration options exist for overcoming this limitation. Below we briefly review the razor clam fishery management and suggest changes and provide a series of restoration options.

Historical & current management regulations

When the razor clam fishery began in Cordova in 1916 there was no size limit or quota. As a result by 1921 a number of diggers were claiming that beds were completely exhausted until the discovery of new beds extended the life of the industry. By 1925 surveys of the Cordova beds by the U.S. Bureau of Fish revealed that razor bed depletions were occurring due to over-harvesting of older, spawning clams, and removal of under-sized, immature clams (Weymouth et al., 1925 pp. 232-234).

These findings led to fishery regulations including minimum length of 4.5 inches with a maximum take allowance of 3% under this size (Nickerson 1975) and 6-week closures during the spawning period (Thompson and Weymouth 1935). Nevertheless, by 1933 takes were considered too high and fishery quotas were also imposed (Nickerson 1975). By the time Nickerson began his study in 1969, minimum length had been lowered to 4 inches. Based on growth and maturity rates, he recommended that minimum length again be increased to 4.5 inches (Nickerson 1975, p. 200).

Both in Prince William Sound and Cook Inlet the razor clam sport fishery, clams must be harvested manually (i.e., no hydraulic or mechanical clam digging). The Alaska Department of Fish and Game regulates a very small, subsistence razor clam harvest east of the line from Point Bentinck to Point Whitshed (Fig. 2, see dashed line). For this area, a permit is required to harvest razor clams, and only razor clams 4.5 inches or longer may be taken or possessed (ADFG 2002). However, for recreational diggers harvesting razor clams from the rest of the Copper River Delta, including Orca Inlet and Pt. Steele on Hinchinbrook Island there are no size limits (Table 5).

There has been considerable debate as to the efficacy of minimum size limits for recreational fisheries. In Oregon, there are regulations that all razors be kept, regardless of size or condition. This regulation is designed is to reduce incidental mortality of undersized clams that otherwise are improperly replanted or injured (McLachlan et al. 1996).

For the Copper River Delta, we recommend that regulations be changed to include a closure period to protect spawning individuals (June 15 – August 30) and a low bag limit (15 razor clams/digger/day). We also suggest that a razor clam fishing permit/harvest record should be required in the Cordova area, so that ADF&G may track harvest level and characterize recreational fishing pressure.

Alternatively or in combination with the above, a rotational plan could be adopted. Under this scenario, the entire harvest area would be divided into a number of smaller harvest areas. A small number would be opened each year with the majority closed. This would then change yearly. The concept is to allow 5-6 year periods between harvest. This would insure spawning from a large percentage of razor clams that have recruited after a harvest period.

Table 5. Sportfish regulations by area, and authors' recommendations for future regulations on the Copper River Delta.

	Prince William Sound		**Cook Inlet**	**Recommended**
Regulation	Orca Inlet, Hinchinbrook	Subsistence Mgmt. Area[1]	Kenai River – Homer Spit	All Copper RD
Special Permit Required	No	Yes	No	Yes
Season	Year-round	Year-round	Year-round	Except 15Jun-30Aug
Size Limit	No	4.5 "	No	4.5" with up to 5 undersized clams allowable.
Daily Bag Limit	No	No	45 clams	15 clams
Possession Limit	No	No	90 clams	30 clams
Rotational Harvest	No	No	No	Yes

Enhancement of razor clam stocks

There are three approaches that could potentially offer success in restoration of razor clam populations: (a) relay and concentrate adults into spawning stock sanctuaries (Peterson et al. 1996), (b) supplement natural levels of recruitment with hatchery raised recruits (Peterson et al. 1995, Brooks et al. in review), or (c) collect and relay natural seed banks to areas that experience higher survivorship (Rickard & Newman 1986, McLachlan et al. 1996) and/or are more easily accessible by fishermen. Each of these mechanisms will be evaluated below.

<u>Relay and concentrate adult razor clams into spawning stock sanctuaries.</u> This method has been recently used successfully by Peterson et al. (1996) to restore populations of bay scallops at Bogue Sound, NC following massive shellfish mortalities from a red tide event. Because fertilization of razor clams occurs in the water column, the proximity of

male and female clams greatly affects the successful production of fertilized eggs and ultimately recruits. When population densities are low, the distance between clams will be high and fertilization success low (i.e. Allee Effect). Aggregating individuals into clusters may create higher production of recruits. This method does have some drawbacks, however. It would require large numbers of transplants to be effective and further experiments on the appropriate minimum aggregation density may be needed. Because the scale of recruitment is unknown (i.e. physical transport models have not been constructed for the area), it would be difficult to assess the ultimate success of this approach.

Supplement natural levels of recruitment with hatchery raised recruits. The seeding of natural beds with hatchery-raised recruits (usually these seed clams are raised from local adult clams to insure no pathogen introductions and genetic similarity) has also demonstrated promise as an effective mechanism to restore shellfish populations limited by recruits (Peterson et al. 1996). In areas where suitable habitat exists and predation levels are low (or can be controlled by simple mechanisms, e.g. vexar netting), replenishment of razor clam stocks using hatchery produced seed clams is an attractive option. Although our project did not have funds to explore this possibility, we believe that seeding of hatchery raised claims is feasible and economic. Hatchery production of razor clams has been accomplished by hatcheries in the State of Washington.

Our next step is to investigate the potential for this approach by coordinating with the Qutekcak Shellfish Hatchery (Seward, Alaska) to determine whether sufficient quantities of seed clams (size range = 5 mm to 12 mm) can be produced to initiate large-scale seedings. Both the hatchery scientists as well as the PI's on this project believe that the hatchery phase will be successful. Stocking density (10, 25, 50 m^2), seed size (5-6 mm vs.10-12 mm), and predator protection (vexar covered bottom vs. uncovered bottom) within plots will be varied as part of the experimental design. We will also evaluate mechanism for decreasing hatchery costs including, seed clam growouts in protected areas along the beaches. All applicable state guidelines for the production and planting of hatchery clams will be met as part of the Qutekcak Shellfish Hatchery contract.

Relocation of naturally set seed clams. The possibility exists that natural seed banks occur in subtidal areas. Along the Washington coast, large aggregations of small razor clams are known to occur at subtidal depths (2 mm clams at 12.2 m below MLLW, 8-12 mm clams at 1.5 m below MLLW; Rickard et al. 1986). If such aggregations occur in the subtidal areas near the three beaches, relocating them to higher tidal elevation away from heavy crab, sea otter, and fish predation may be an effective mechanism to enhance the fishery. This option merits further investigation. If it is feasible, a cost comparison to hatchery operations should be conducted to evaluate the economic feasibility.

SUMMARY OF FINDINGS AND RECCOMENDATIONS

- Razor clam populations in the Cordova District have declined due to a combination of factors. Chief among these are over- harvesting and habitat change.

- The return of the fishery may be impeded by changes in predator abundances and unregulated recreational harvest.

- Our experiments imply that the razor clam fishery has the potential to be restored, but:

  - It needs better management
  - A source of hatchery seed clams will be necessary
  - Timing of seeding trials is critical
  - Protection from predators is necessary for spawning sanctuaries and seeding efforts

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