CORAL, CRABS, AND CONSERVATION

Managing Aleutian King Crab Through the Preservation of Cold-Water Coral Gardens

Team: The Nefarious Dawgsharks

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ABSTRACT

The king crab fishery is a vital part of Alaska's economy, particularly within the Aleutian Island chain. Crab in this area have been shown to depend upon cold-water coral gardens for shelter from the vast array of species that use them for a food source. The corals themselves are very slow growing and as such are vulnerable to a variety of threats; the most dramatic is bottom trawling – this form of fishing can destroy vast swaths of coral gardens. In order to protect Aleutian crab stocks, several measures are proposed, including spatial trawl restrictions and artificial reef programs.

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INTRODUCTION

The Aleutian Archipelago is rooted on the Alaska Peninsula and extends 1,900 km to the Kamchatka Peninsula in Russia (Stone 2005). This row of islands, supported by the Aleutian ridge and separating the deep North Pacific Ocean/Gulf of Alaska (average depth 4,000 meters) and the shallow Bering Sea (average depth 1,550 meters) [Figure 1], is an area of strong tidal currents and intense nutrient exchange (Stone 2006). These oceanographic and geologic conditions, as well as the presence of exposed rock substrate from volcanic activity, create an ecologically rich area that supports a number of commercially valuable stocks of fish such as pacific cod, black rockfish, walleye pollock, pacific ocean perch, atka mackerel, arrowtooth flounder, and golden king crab (Stone 2005). These species are harvested using bottom-contact trawls, single-pots, longlines with hooks, and longlines with crab pots The fisheries operate at depths up to 950 meters with the greatest efforts shallower than 200 meters. The crab pot fishery ranges between 100-750 meters with the greatest efforts between 200-500 meters (Stone 2006).

A unique feature of the Aleutian Archipelago is the presence of highly diverse and abundant coral and sponge communities (often referred to as coral gardens) (Heifetz et al. 2009). These corals run parallel to the Aleutian Archipelago with most distribution along the south shore [Figure 1]. The Aleutian coral gardens may be some of the most diverse in the world. Already 86 different taxa have been discovered including stolon corals, soft corals, sea whips and sea pens, gorgonian corals, stony cup corals, hydrocorals and black corals. 25 of these may be endemic to the Aleutian chain (Heifetz et al. 2005, Stone 2006). Corals inhabit depths from 100-800 meters and appear to be most abundant between 100-200 meters (Stone 2006, Heifetz et al. 2009). There is significant overlap between coral distribution and fishing efforts.

The complex benthic habitats of coral gardens serve as important nurseries for juvenile groundfish and crab by providing a buffer from strong currents, shelter from predators, and habitat for prey (Pirtle 2010) [Figure 2]. The coral gardens are composed of long-living (75-125 years) and slow-growing species that thrive on organic detritus and plankton transported by strong, deep sea currents (Andrews et al. 2009, Heifetz et al. 2009). The coral and sponge communities are highly susceptible to damage by fishing gear and recovery may be extremely slow (true rates are unkown) (Reynertson, 2010). Damage to the coral ecosystem can negatively affect the species supporting lucrative commercial fisheries.

Given the strong association of target species with coral and sponge communities, fishing efforts result in major anthropogenic damage to the Aleutian coral gardens (Heifetz 2002, Stone 2006, Heifetz et al. 2009). Harvesting techniques, especially trawling, are capable of damaging and removing large tracts of deep-water corals [Figures 3, 4], destroying important habitat for juveniles and prey species (Heifetz et al. 2009). Bycatch of corals and sponges in the Aleutians have been reported back to the early 1900s when trawling began in the area. The US National Marine Fisheries Service estimates that 82 metric tons of coral is removed from the seafloor each year by commercial groundfishing (Stone 2006).

This research paper analyzes the association of the golden king crab fishery and the Aleutian cold-water coral and sponge communities to recommend an improved ecosystem-based management plan that incorporates cold-water corals into the golden king crab fisheries. We review the historical and economic significance of golden king crab (the most economically important species found as juveniles in the reefs), primary threats to the corals, and devise a multi species management plan that combines current regulations with new fishing procedures and materials in order to reduce damage on deep-water corals while maintaining a high catch rate.

ALEUTIAN COLD-WATER CORALS

Ecology

Numerous families of coral can be found near the Aleutian Archipelago (Stone 2005). These include bamboo, black, paragorgian, primnoa and strong, but the most common are gorgonians (45species) and stylasterids (25species; Stone and Shotwell 2007). These corals bear a resemblance to tropical shallow water reefs, which are characterized by structural complexity, rigid framework, much topography, and a high level of biodiversity. They differ in their non-photosynthetic (azooxanthellic) characteristics. Many of corals live at depths deeper than the range of light penetration. Cold water corals use currents and passive methods of feeding rather than photosynthesis for energy. Unlike tropical reefs, the underlying framework of coral gardens is abiotic: exposed bedrock, boulders, and cobbles (Stone 2006).

Distribution

A major shift in coral diversity occurs near the eastern Aleutians at a longitude of 169° W. Much greater coral diversity is found west of this line compared with the area east of it (Heifetz et al. 2005). In the eastern Aleutian Islands, gorgonians are widely distributed along the continental shelf and upper slope, and few bamboo corals have been observed. Stylasterids can be found in great quantities on the southeastern Aleutian Archipelago (Stone and Shotwell 2009)

Corals are widespread and in great quantities around the western Aleutian Islands. This area features distinct coral gardens typically located in small patches at depths between 100-350 meters. These coral gardens feature high coral abundance (3.85 corals m^2). Gorgonians (1.78 colonies m^2) and stylasterids (1.46 colonies m^2) are especially ample in these areas (Stone and Shotwell 2009).

On average, corals found in the western Aleutian Islands have a greater depth distribution than corals found on the eastern side, or anywhere else in Alaska. Primnoa spp. and Paragorgia spp. can be found up to depths of 1,500 meters. Black and bamboo corals have been documented at depths between 400-3,000 meters and grow on rough terrain. Stylasterids are the second most common coral in the region and have been observed at depths of 10-2,100 meters.

Stony corals have a broad distribution in western Aleutian Islands. They have been collected at depths between 240-4,500 meters in the Aleutian Trench. True soft corals are also abundant and have been observed at depths between 10-2,000 meters. Pennatulaceans have been observed in extensive groves as deep as 3,000 meters. They grow in areas of soft sediment on both the continental shelf and slope.

In the Aleutians Islands, the most frequently trawled depths are between 50-100 meters and up to 500 meters. These targeted trawling depths align closely with the distribution of cold-water corals, posing serious risk of ecological interference from fishing gear.

<u>Species Association</u>

Many species targeted by commercial fisheries, especially fish and crabs, use cold-water coral habitats. These animals, particularly juveniles, use corals as refuge and as focal points of high prey abundance. It is supposed that shelter-seeking fish such as rockfish use the coral habitats as spawning and breeding sites (Stone and Shotwell 2007) [Figure 2]. Of the 35 species harvested commercially in Alaska, 85% spend some phase of their life in deep-water habitats, including areas inhabited by cold-water corals (Stone and Shotwell 2007).

In 2004, NOAA researchers investigated the association between Alaska's commercially harvested species and corals (including other structure-forming invertebrates) in the central Aleutian Islands. They analyzed video footage of the seafloor in sites up to 3,000 meters in depth and found 84.7% of Alaska's commercially important fish and crabs to be in association with corals and other fixed, shelter providing invertebrates. These include pacific cod, black rockfish, walleyed pollock, pacific ocean perch, atka mackerel, arrowtooth flounder, and golden king crab. All seven species of rockfish (Sebastes) were found in high association with corals. Given this association, it is vital to include corals into the management plans of these fisheries.

HISTORY

The golden king crab (*Lithodes aequispinus*) fishery in the Aleutian Islands is unique among western region king crab fisheries. Because of its high stock abundance, the fishery has never failed to open. Golden king crab were first taken in 1975/76 as incidental harvest during the red king crab fisheries in the Adak and Dutch Harbor areas, but directed fishing for golden king crab did not occur in either area until the 1981/82 season (Bowers et al. 2011). They require the use of longline rather than single pot gear, and it is the only fishery in Alaska where longline is the only legal gear type. Only males that are at least 6 inches wide may be taken.

The golden king crab fishery was established in 1981/82. Annual retained catch peaked during the 1985/86–1989/90 averaged 11.9 million pounds (Pengilly 2011). However, the retained catch dropped sharply from the 1989/90 to 1990/91 season, and the average annual retained catch from 1990/91–1995/96 was 6.9 million pounds. Management towards a formally established guideline harvest level (GHL) was introduced for the first time in the 1996/97 season with a guideline harvest level of 5.9 million pounds; this was subsequently reduced to 5.7 million pounds for the 1998/99 season [Figure 5]. The guideline harvest level (or, since the 2005/06 season, the total allowable catch (TAC)) remained at 5.7 million pounds through the 2007/08 season, but was increased to 6.0 million pounds for 2008/09–2010/11 seasons. Average annual retained catch for the period 1996/97–2007/08 was 5.6 million pounds and rose to 5.8 million pounds in 2008/09–2009/10 (Pengilly 2011).

Catch per longline pot lift of retained legal crab decreased from the 1980s into the mid-1990's, but increased steadily following the 1994/95 season, and then increased rapidly during the 2005/06 season with the introduction of the Crab Rationalization program. This program changed the crab industry from a more competitive derby style season to an established quota system (NOAA 2011). Non-retained bycatch occurs mainly during the directed fishery. Although some minor levels of bycatch can occur during other crab fisheries, there have been no such fisheries classified as direct fisheries since 2004/05.

Bycatch also occurs during fixed-gear and trawl groundfish fisheries. Bycatch is the unintentional catch of marine species while intending to catch another species. This can refer to a nontarget species being kept and sold, the unintended species/size/sex of a species, and the catch of invertebrate species including corals. All of these can have a significant social, environmental, or economic impact on a species. Efforts to decrease bycatch, or to take into account the effects it can have, should be included for species management plans. Although bycatch during groundfish fisheries exceeded 100,000 pounds for the first time during 2007/08 and 2008/09, that bycatch was less than 10% of the weight of bycatch during the directed fishery for those seasons, and estimated total bycatch in groundfish fisheries during 2009/10 was lower at 62,000 pounds. Annual non-retained catch of golden king crab during crab fisheries has decreased relative to the retained catch and in absolute numbers and weight since the 1990's (Pengilly 2011). Estimated total fishery mortality (retained catch plus estimated bycatch mortality during crab and groundfish fisheries) has ranged from 5.8 million pounds to 9.4 million pounds during 1995/96–2009/10.

ECONOMICS

The value of the golden king crab market is determined by a number of factors. For one, golden king crab are smaller the other species of Alaskan crab and have a milder flavor (FishEx 2011). However, golden king crabs are the most abundant species in Alaska and can be sold fresh instead of frozen in brine (FishEx 2011). Golden king crab has a lower price point, which means that it is particularly valuable in smaller businesses where price point is a major consideration. Because of this, the golden king crab market is growing in the continental United States and exports to places like Japan (FishEx 2011).

In the 1980's, the red king crab stock collapsed after the largest season worth $115.3 million, at that time, the golden king crab fishery started up in Alaska and has been steadily rising ever since (NOAA Fishwatch 2011) [Figure 5]. Although it still earns significantly less then Bristol Bay red king crab [Figure 6], and Bering Sea Snow Crab, [Figure 7] the processing capacity is there in places like Dutch Harbor to make it a profitable fishery in the near future. Modern and exact data is confidential due to the switch to rationalization (Federal Register 2011).

Although employment size and positions have dropped in 2005, they rose through 2009 and the mean crew size stayed about the same [Figure 8]. Employment in this fishery will steadily increase because days spent fishing has been increasing as well [Figure 9].

Along with market prices, income for fishermen has been on the rise since 2006. In 2008, the mean captain payment per vessel was $0.15 million while the mean crew payment per vessel was $0.34 million [Figure 10].

THREATS

Given the importance of corals to juvenile and grown king crab, it is vital to ensure healthy coral habitats. This is a challenge due to the many threats to the corals. These threats include the effects of ocean acidification, bycatch, habitat degradation and pollution.

Ocean Acidification

As pH levels in the oceans rise due to absorption of carbon dioxide, calcareous organisms including corals, coccolithophores, algaecoralline algae, foraminifera, shellfish, and pteropods have a more difficult time forming their shells and skeletons. When exposed to increased acidity levels, these organisms experience reduced calcification and increased levels of dissolution resulting in thinner outer shells. Corals with inadequate shells and skeletons are more vulnerable to damage. Because they take a long time to recover, anything else that further hinders their growth can have severely damaging effects on the coral ecosystems.

Reduced growth not only affects the coral as a key habitat, but also the inhabitants living throughout the coral gardens. The Kodiak Laboratory is currently studying the effects of high CO_2 levels on the larval and reproductive systems of red king crab (AFSC 2011). High levels of CO_2 are hypothesized to affect king crab morphology and mass, decrease carbon and nitrogen content, and reduce survival rates. Although this study is being conducted on red king crab, the effects on golden king crab should be similar. Any of the effects can have negative impacts on the lucrative king crab fisheries.

<u>Bycatch from other Fisheries</u>

Trawling bycatch of golden king crab occurs during groundfish fishing. Less than 2% of total annual weight is accounted for by bycatch (Pengilly 2011). To obtain this information, all fishing vessels disclose information regarding number of pounds of unintended crab caught. In the first three years, the information is unreliable due to inaccurate data [Figure 11].

<u>Habitat Degradation from Fishing Gear</u>

The abundance of highly diverse corals in the Aleutian Islands area causes a wide range of issues for both conservation of habitat and the impact it can have on maintaining commercial fisheries. Crab and fish species use the corals as important habitat for reproduction and protection as they grow up. Because these corals and sponges are long lived and slow growing, their recovery from gear damage is slow, causing a lack of habitat and protection for many species. Although measures to protect this habitat have been implemented, the continual challenge to protect the habitat is still ongoing.

Heifetz et al. (2007) used video footage taken by the ROV Jason II for various locations throughout the Aleutian Islands. They analyzed the damage of corals due to fishing techniques in both heavily fished areas as well as in non-fished areas; their findings are summarized below.

Bottom trawling occurs mostly in depths of 75-200 meters but can reach up to 325 meters, targeting Atka mackerel, rockfish, and Pacific cod, a high portion of corals and sponges are damaged within these depths [Figure 12]. Although fast current and landslides naturally cause some of the damage, most of the damage is done by bottom contact gear. Trawling gear causes both long striations on the sea floor from the trawl foot rope and gouges from the trawl doors. Altogether, the amount of gear contacting the bottom floor may reach up to 110 meters, causing heavy damage to the seafloor and the corals. This damage occurs everywhere in heavily trawled areas except areas with steep or irregular bathymetry. In these places, trawl gear can either be lost or damaged. Due to the extensive width of the trawl gear, trawling accounts for most of the coral habitat damage.

Most longlining occurs at depths of 75-200 meters for Pacific cod and 300-750 meters for sablefish. This method of fishing uses anchors to weight down mainlines that can often reach up to 20 km across the seafloor. There are two ways that longlining can damage the seafloor: the weights can drag across the seafloor and the longline hooks can entangle in coral during retrieval or while the fish caught try to escape (Stone 2006). The area of damage can occur in areas not reached by bottom trawling, making the total area affected extremely large.

Longlining with crabpots targets golden king crab at depths of 150-600 meters. The amount of damage it can do depends on the where the retrieval occurs and how strong the winds are. If the pot is retrieved in an area that is steep or in an area with high winds where it is dragging, the amount of damage to the seafloor increases. Given the overlap in fishing areas, it is difficult to determine the effect of one specific gear type on the corals. Heifetz et al. (2009) indicate that trawling can mask damage by the other types of gear.

Pollution

Point-source pollution discharged in the coastal areas will have little effect on deep-sea corals in Alaska. Major damage comes from the introduction of untreated sewage and chlorine into the ocean (Heifetz et al. 2009). This causes increased phosphate nutrient enrichment that increase biological production resulting in algal blooms which, when die, are deadly to coral because bacteria decomposition uses up oxygen in the water (Heifetz et al. 2009). Chlorine in sewage waste is toxic to marine life can affect both corals and other animals.

The majority of fishing is in the 75-300 meter region and greatly stresses the coral; the damage can cause a huge decrease in habitat for king crab and other animals. A successful management plan needs to be taken into account to balance the amount of fishing with the amount of habitat available for animals that need them.

MANAGEMENT PLAN

Any ecosystem-based management plan is, by nature, multifaceted. Our plan incorporates several fractions; each designed to address the economic, ecological, or social aspects of both the bottom trawl fishery as it is now and as it may become to compensate for other industries. These recommendations have been created with the intention that they be implemented as a whole; however, they have also been designed so that they can be put in place separately.

Artificial Reefs

The most ecologically based sector of our management plan is an experiment of sorts: artificial reefs. Made of everything from specially designed concrete blocks to old oilrigs and subway cars, these structures have proved a great success in more tropical waters, where they provide corals with a surface to latch onto and grow (New Jersey Department of Fish and Game 2010).Whether or not northern corals require the same support from artificial bases as their southern counterparts, these structures will still provide cover for the young of commercial species of interest. Since northern corals are not photosynthetic (Freiwald 2003, 2004), corals may be able to grow inside the artificial reefs. This idea advocates the use of hollow artificial reefs in polar waters, for instance, a derelict boat destined for scuttling or a hollowed design specific to the task.

In addition to providing new habitat for crabs and other ecologically and economically significant species, artificial reefs may also be used as barriers to protect existing reefs. This has already been proven in warm water areas (Fabi and Fiorentini 1993) and may have even greater viability in the north, given one of the greatest threats to corals: Trawling. A trawler that pulls up an extremely heavy, gear-damaging, block of twisted metal or concrete is not likely to risk his gear by resetting in the same area. There is also the possibility that trawlers would see an artificial reef on a depth sounder or fish finder and avoid setting in the first place.

The potential costs of this plan range from thousands to millions of dollars, depending on the extensiveness of the plan and type of materials used. For instance, covering an area of one square mile with a cheaper brand of prefabricated artificial reef would cost about $300,000; scuttling a single ship in an ecologically responsible manner costs as much as $20 million, with more common costs around $200,000 (Associated Press 2006, ReefBall Foundation 2007). Regarding the cost of prefabricated reefs, it is important to consider that it would not be necessary to completely cover a mile with reefs – a barrier or dispersal over several miles would be a more apt use for that volume of concrete.

Spatial Restriction of Trawling

A successful fisheries management plan should balance the ecology and economy of Western Alaska and the Aleutian Islands. The most straightforward, and likely the most effective, solution is that bottom trawling be restricted not only within the currently protected areas around the Aleutian Islands but also other areas that are determined to contain coral gardens. This approach is already in effect to some degree – in 2005 the North Pacific Fishery Management Council enacted a ban that covers many areas heavily occupied by corals, however, many more are excluded (Stone 2006, Heifetz et al. 2009). In order to assist the bottom trawling industry, we may open areas currently under the blanket ban that are proven NOT to contain coral gardens, in addition to closing some currently unprotected areas that actually do contain corals. In effect, we would like to impose a patchwork of closed and open areas along the Aleutians and into the Western coastline instead of the blanket ban currently in place. A GPS (Global Positioning System) database could be put in place in order to outline protected and open areas to trawlers easily and effectively. Alternatively, existing charts could be updated to show coral gardens in addition to the current landmarks. This approach would allow crab fishing to continue in the Aleutian Islands while protecting high biodiversity nursery habitats. Because there is not currently an existing catalogue of such habitat, more research will have to be conducted into coral distribution.

Counter intuitive though it may seem, measures to restrict bottom trawling could actually be beneficial to Alaska's fishing economy. As described previously in this paper, red and golden king crab depend on healthy cold water coral and sponge ecosystems, primarily as essential habitat for juveniles and prey species. When bottom trawlers flatten coral gardens in an attempt to reach their target species, the destruction they cause is likely detrimental to their own future catches since young fish have been shown to utilize corals as cover from larger fish during the stage in their lives when they are little more than zooplankton, providing for nearly every large species in the area (North Pacific Research Board 2010). This destruction of future stocks (and economic prosperity) through mismanagement, it may be argued, is very near poetic justice, and is not the concern of anyone outside of the trawling community. If the effect were only on the trawling community, then this argument would have far greater standing, however, given the presence of other commercially valuable species (namely, golden and red king crab) in coral gardens this sort of "sole responsibility" position becomes indefensible.

Economically, this ban offers a counter intuitive conclusion: economic benefit derived from economic restriction. The current ban on Aleutian trawling has been estimated to cost at most $2.4 million dollars (Reuters 2006). However, this figure only looks at gross bottom trawl profits and does not consider gains in other fishing industries due to the preservation of nursery habitats, which may outweigh any losses sustained by bottom trawling. Neither the current ban nor the new proposal affects pollock, the most profitable trawl fishery in Alaska; pollock are captured with mid-water trawls (Monterey Bay Aquarium 2009, NOAA Fishwatch 2011).

<u>Crab Hatcheries</u>

This solution focuses on the promotion of the crab fisheries. Research is currently being done at the Alutiqq Pride shellfish hatchery in Seward toward the viability of king crab hatcheries to improve the overall health of king crab stocks (Alaska Sea Grant 2007). If this proves a possible augmentation to wild stocks, the locations of known coral gardens could be used as release points for young crab in order to improve the effectiveness of the hatchery system. Precedents for successful hatchery systems with remote release sites are already in place in Southeastern Alaska and Prince William Sound (Heard 2004).

Because there are no current crab hatcheries in place, the possible cost is difficult to figure. However, the Alutiqq Pride shellfish hatchery has an annual overhead of approximately $300,000 (Alaska Office of Management and Budget 2010).

Tax and Funding for Programs

Given the likely damage to crab stock through bottom trawling, we wish to supersede the benefit of bottom trawling with the economy of the entire state, to which crabbing has a greater importance. We move for reasonable restrictions to be put in place on bottom trawling, including area restrictions.

It requires research to better understand the deep water coral ecosystems and the implications of any managerial action: discover the exact ranges of corals, better comprehend how animals use corals, and increase understanding of the significance of corals in the life cycles of both crabs and groundfish. This research will be expensive and difficult to conduct, and will require more funding in a shorter amount of time than the federal government usually gives to anything (with the exception of defense). In order to raise money, we also propose a tax on crabbing – no more that 2% of gross – to go towards research, mapping, and placement of artificial reefs. Even at such a modest percentage of gross, this tax could raise as much as $2.5 million from crabbing (numbers based on 2010 gross revenue of king crabbers and in Bristol Bay and the Aleutian Islands, State of Alaska Bureau of Fisheries Statistics 2011). This money will go towards the implementation of artificial reefs, enforcement of the special restrictions, and wages of observers on trawlers. A portion of this money could also go towards the education of fishermen on the benefits of preserving reefs.

There is another funding source specific to artificial reefs: the U.S. Maritime Administration Artificial Reef Program, a subset of the National Defense Fleet Ship Disposal Program. Sponsored by the federal government, this program provides large ships to state governments for sinking. While the federal government does not absorb the cost of the transfer itself, it provides ships that have already been stripped down and thereby absorbs a sizeable portion of the overall cost of scuttling a ship (U.S. Department of Transportation: Maritime Administration 2009).

CONCLUSION

Data has shown that king crab is an integral part of Alaska’s economy. Research has shown that juvenile king crab (and other commercially viable species) is highly dependent on cold-water corals for cover from predators, and thus cold-water corals are vital to the future health of crab stocks (and the stocks of other Alaskan species). These corals are slow growing, and as such, are vulnerable to damages, most notably from bottom trawling (which churns the seafloor and destroys any corals present). In order to preserve these corals, and further the Alaska crab fishery in the face of threats known and unknown, several measures have been proposed, each with its own strengths and weaknesses. Each piece of this plan has been formulated to work independently and together with the other components, in order to account for the possibility that it may not be practical or feasible to implement all parts at once. These management solutions may provide assistance with maintaining a sustainable and profitable fishery and an intact ecosystem in the Aleutian Islands.

FIGURES

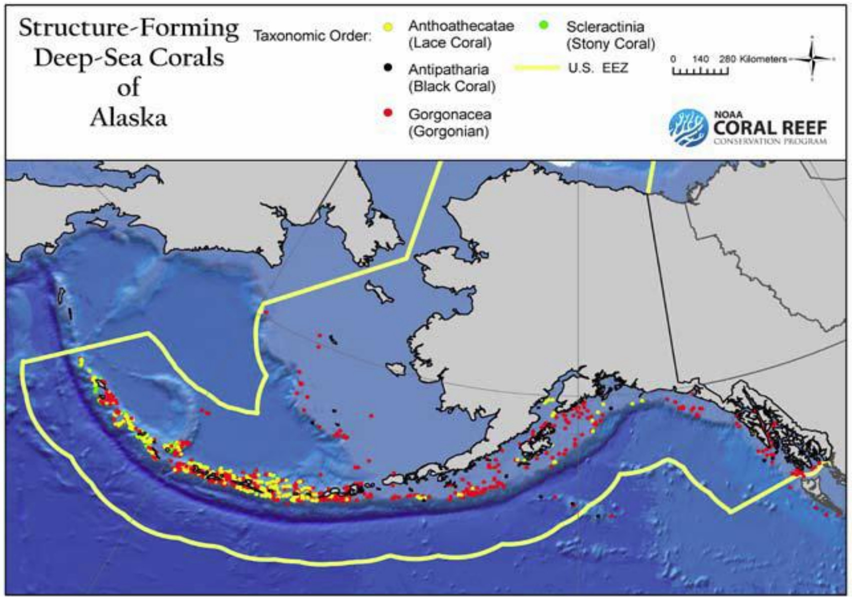

Figure 1. Bathymetry of the Gulf of Alaska and Bering Sea. Distribution of Structure-Forming Deep-Sea Corals of Alaska. Location data are incomplete for corals other than stony and gorgonian corals (NOAA's Coral Reef Conservation Program, 2010)

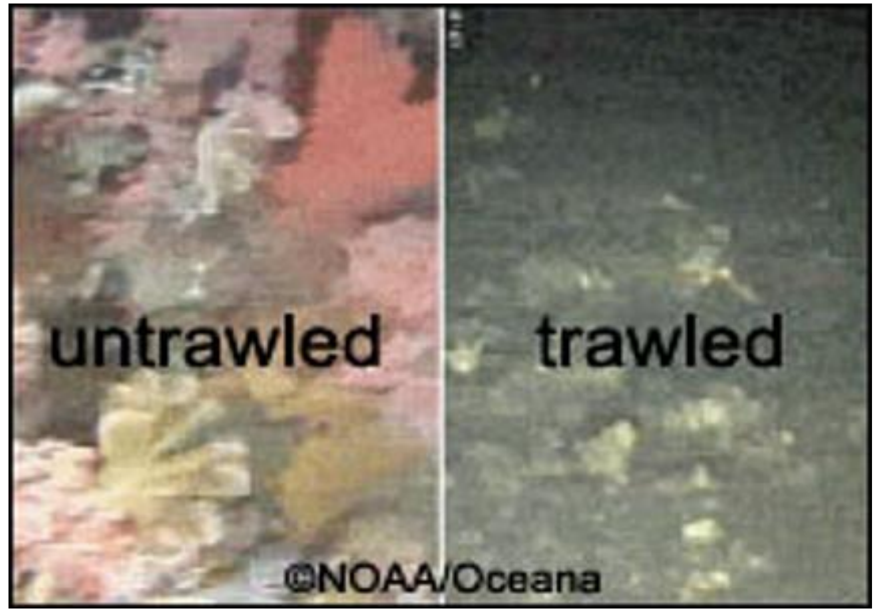

Figure 3. Damage of Deep Sea Corals from Trawling (http://cleanet.org/images/research_education/corals/effects_trawling.jpg)

Figure 2. A Darkfin Sculpin (*Malacocottus Zonurus)* finds shelter under a bubblegum coral (*Paragorigia arborea*) (Stone and Shotwell 2009)

Figure 4. Unidentified Coral bycatch from trawling (http://terranature.org/Mfish_1_redCoralZoom.htm)

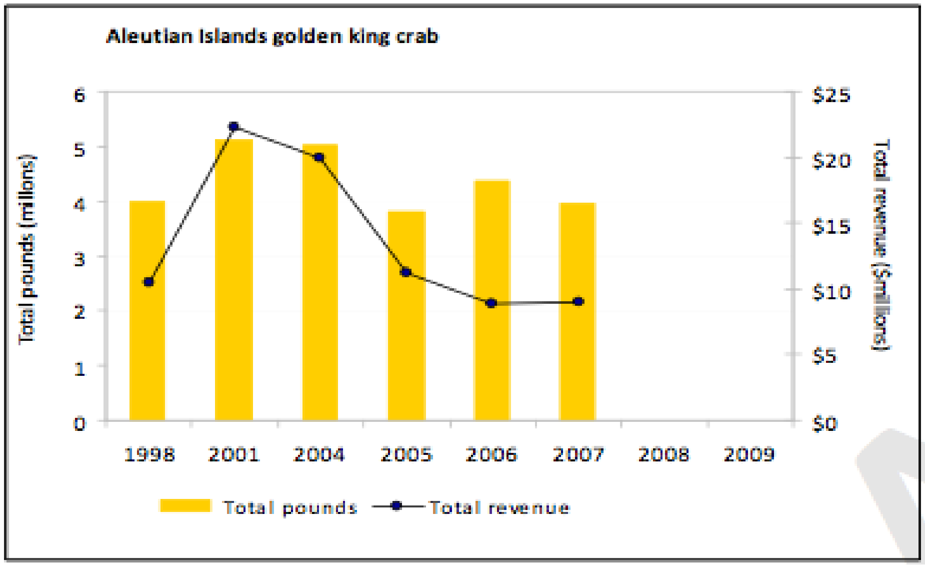

Figure 5. Total pounds and revenue for golden king crab (Garber-Yonts and Lee 2010)

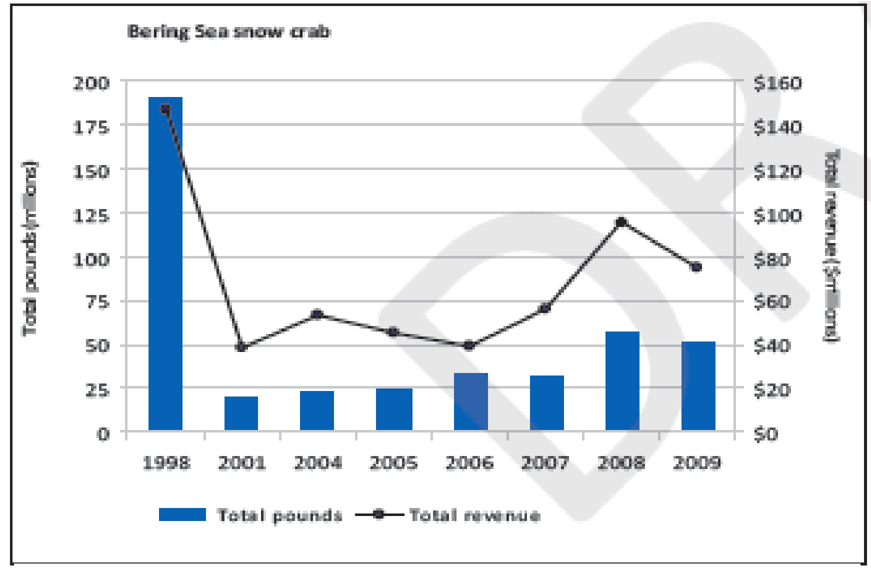

Figure 7. Total pounds and revenue for snow crab (Garber-Yonts and Lee 2010)

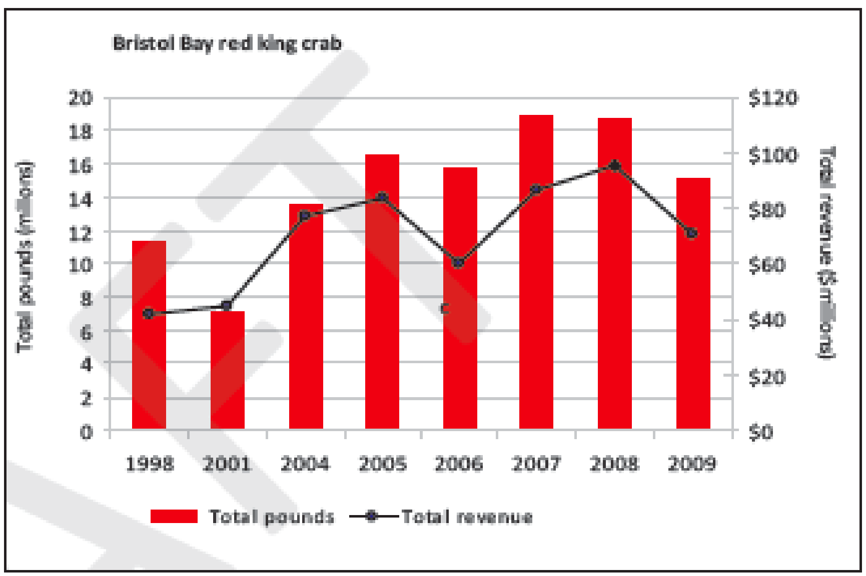

Figure 6. Total pounds and revenue for red king crab (Garber-Yonts and Lee 2010

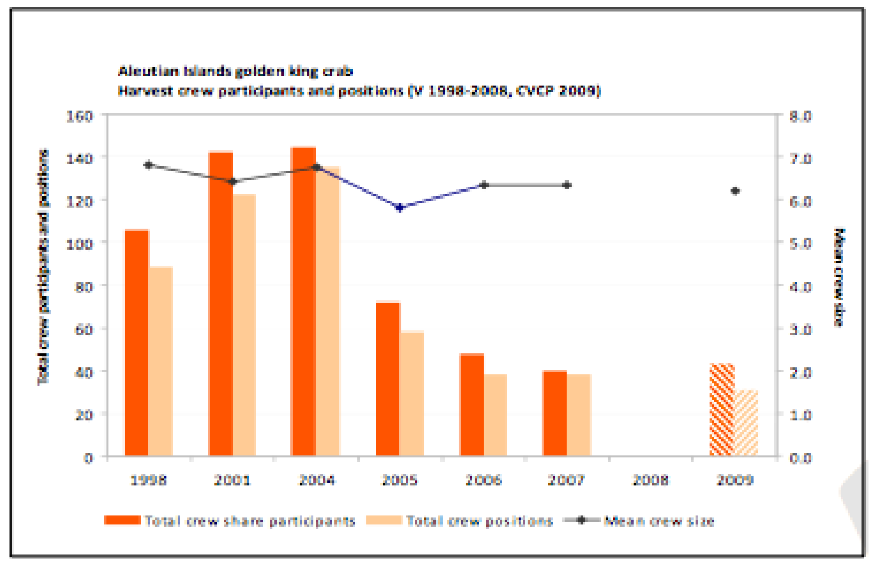

Figure 8. Golden king crab fishery participants and positions (Garber-Yonts and Lee 2010)

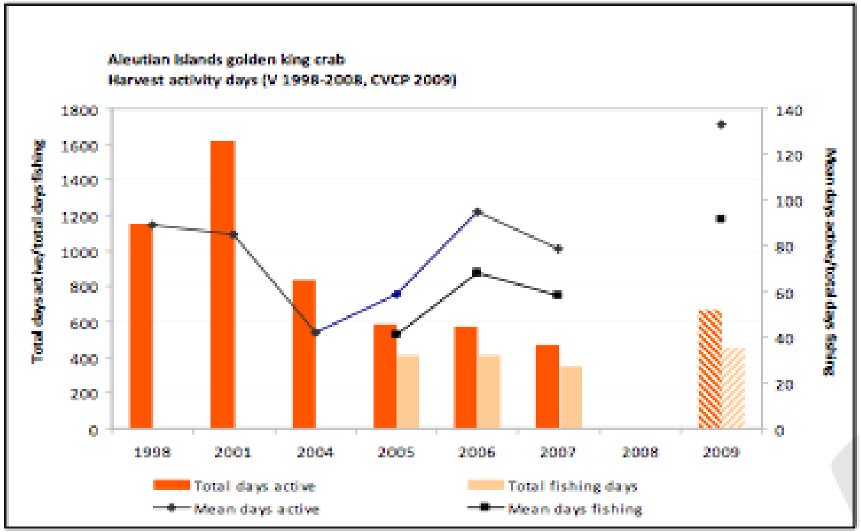

Figure 9. Golden king crab days active and fishing (Garber-Yonts and Lee 2010)

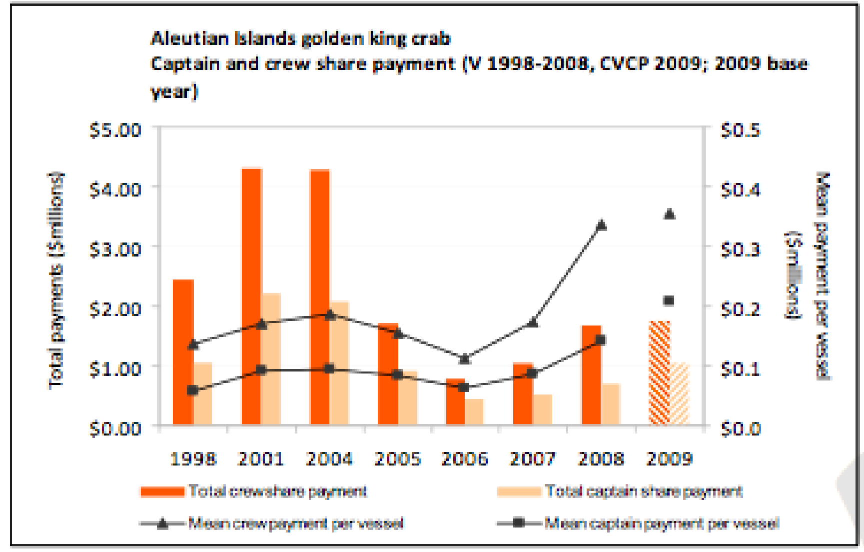

Figure 10. Golden king crab crewshare and captainshare payments (Garber-Yonts and Lee 2010)

Year	Fixed	Trawl	Total Bycatch	Total Bycatch Mortality
1991/92	0	0	0	0
1992/93	5	3	7	4
1993/94	3,960	8,164	12,124	8,511
1994/95	1,346	2,674	4,020	2,812
1995/96	367	5,165	5,532	4,315
1996/97	26	13,862	13,887	11,102
1997/98	539	1,071	1,610	1,126
1998/99	3,901	1,381	5,282	3,055
1999/00	10,572	1,422	11,995	6,424
2000/01	7,166	669	7,836	4,119
2001/02	1,387	417	1,804	1,027
2002/03	75,952	871	76,823	38,673
2003/04	86,186	1,498	87,684	44,291
2004/05	2,450	2,452	4,903	3,187
2005/06	1,246	4,151	5,397	3,944
2006/07	72,306	3,077	75,382	38,614
2007/08	254,225	3,641	257,867	130,026
2008/09	108,683	22,712	131,395	72,511
2009/10	44,226	18,061	62,287	36,562

Figure 11. Golden king crab bycatch for fixed and trawl gear in the Aleutian Island region (Pengilly 2011)

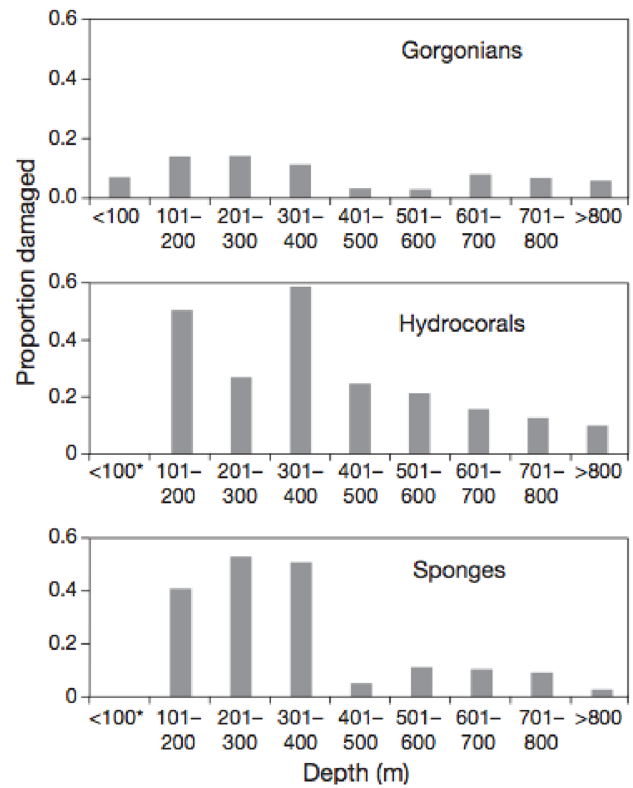

Figure 12. Percent of damage to cold-water corals at different depths from fishing gear (Heifetz et al. 2009)

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