Multispecies modeling of Atka mackerel/Pacific cod interactions in the Aleutian Islands

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Steller Sea Lions, Pacific cod, and Atka mackerel are part of a complex, interrelated food web in the Aleutian Islands (Fig. 1). The effects of fishing policy changes, therefore, should be evaluated in both single-species and multispecies contexts. In particular, Atka mackerel are a central species in the Aleutian Islands food web, serving as both predator and prey for many species, as well as being the source for a commercially important fishery (Fig. 2). Additionally, Pacific cod play a strong role as a predator within the system, as well as being a food source for marine mammals. In order to evaluate the effects of attempting to direct prey to Steller Sea Lions through fishing reduction or area closure for either species, it's important to evaluate how these species might interact by using existing multispecies and ecosystem models developed for the Aleutian Islands.
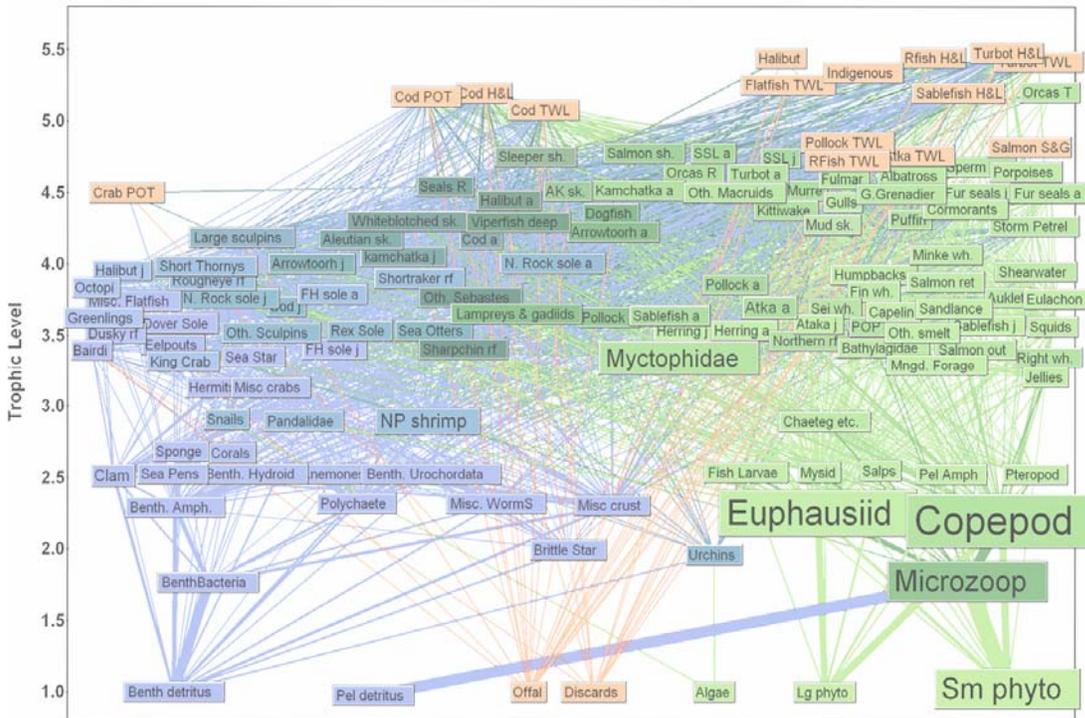
Figure 1. The food web of the Aleutian Islands shelf (management areas 541-543, <500m depth) ecosystem, as modeled for the early 1990s time period by Ortiz (2007) and Aydin et al. 2007. Blue coloration indicates the benthic energy pathway; green coloration indicates the pelagic energy pathway. Fisheries are shown in orange.

Current multispecies models of the Aleutian Islands are not directly and immediately well-suited to simulating or making full predictions for closures affecting only a portion of the Aleutian Islands, such as a closure of Area 543 to Atka mackerel and Pacific cod fishing. The existing simulation (dynamic) models treat the Aleutians as a whole as a single stock area for each species and are not directly geared for simulating partial

closures. Furthermore, as a comparison point, the best available science on Pacific cod overall biomass is a combined Bering Sea/Aleutian Islands stock assessment model (e.g. Thompson et al. 2009) and make limited use of Aleutian Islands data, thus overwhelmingly reflecting Bering Sea dynamics. Finally, as described in Kinzey and Punt (2009), there is considerable uncertainty as to functional responses between predators and prey which requires careful analysis of the statistical properties of multiple alternate models.
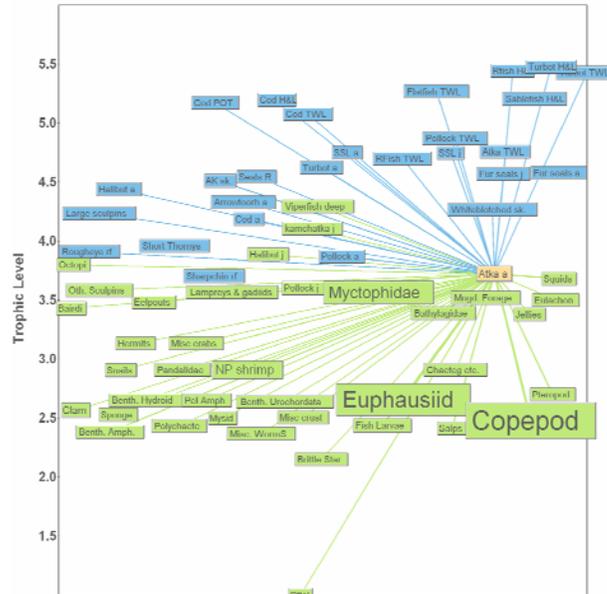
Figure 2. The position of Atka mackerel in the food web of the Aleutian Islands shelf (management areas 541-543, <500m depth) ecosystem, as modeled for the early 1990s time period by Ortiz (2007) and Aydin et al. 2007. Blue coloration shows predators of mackerel, green coloration shows prey. Species not directly connected to Atka mackerel are not shown.

The capacity exists at AFSC adjust existing models to perform said analyses for limited-area closures with multispecies and food web models, and for performing a statistical examination of functional responses using the Kinzey and Punt (2009) multispecies model, in a 6-12 month time frame. In the mean time, this report focuses on qualitative inferences made from a combination of whole-Aleutians food web model results and data specific to the western and central Aleutians.

As described in Aydin et al. (2007), Atka mackerel are an important prey for many predatory species, particularly Steller sea lions and Pacific cod (Fig. 3). Summed across the Aleutian Islands, and across all age/size classes of species in the populations, cod, SSL, and fisheries are similar in magnitude as quantified sources of mortality on Atka mackerel. Therefore, if fishing is decreased on Atka mackerel, either in part or all of the Aleutian Islands, it is reasonable to have the general expectation that more Atka mackerel would be available to SSLs, but also to cod and other groundfish such as Pacific halibut and arrowtooth flounder. It is uncertain, on both short and long-term time scales, whether one of these predatory species would "win" the competition for the released prey.
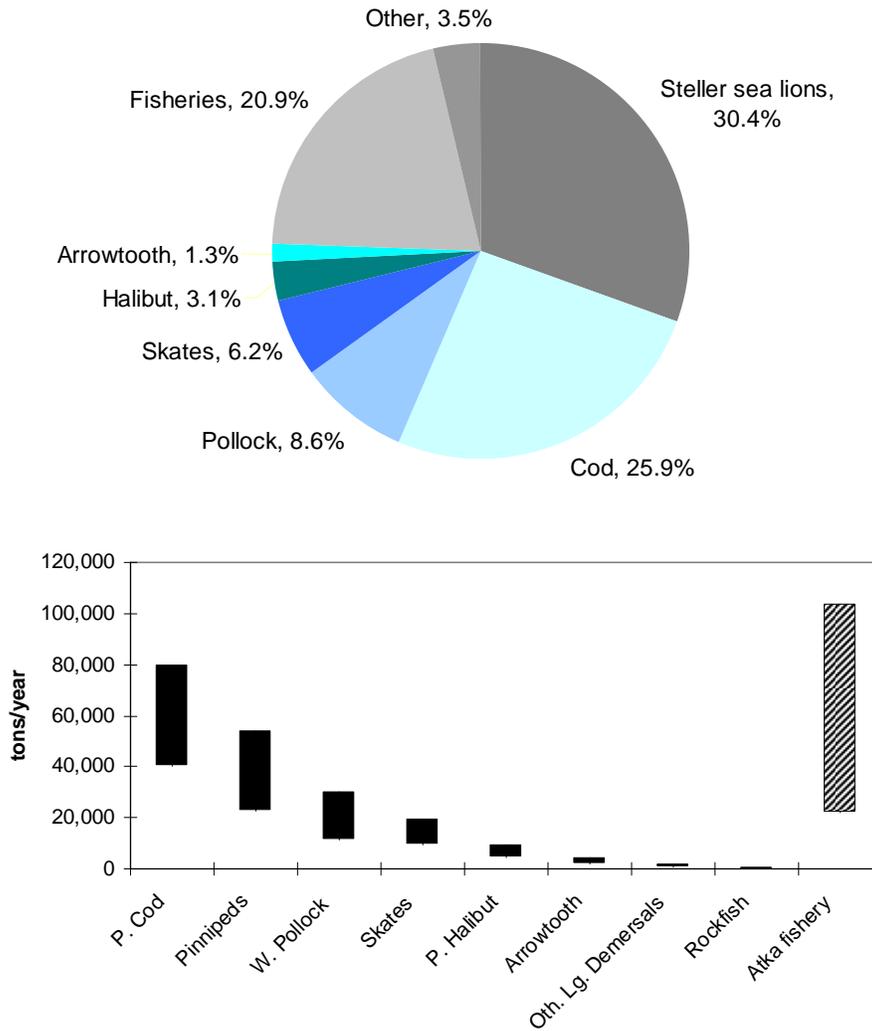
Figure 3. Consumption of Atka mackerel ≥20cm fork length by predators (including fisheries) in the Aleutian Islands during the early 1990s). Top graph shown percentages by point estimate (Ortiz and Logerwell 2010). Bottom graph shows credible range of consumption rates (tons/year) as estimated by Aydin et al. (2007). Fisheries range spans the minimum and maximum annual catch for the years 1990-2007. Over 95% of consumption by "pinnipeds" in this figure is attributable to Steller sea lions.

In particular, Pacific cod itself is a top predator with a fully developed commercial fishery in the Aleutian Islands (Fig. 4). If fishing is reduced simultaneously on Pacific cod and Atka mackerel, it is possible that the proportion of mortality removed from Pacific cod, and the increase in mortality on Atka mackerel that might arise as cod increased, would be greater than the mortality removed from Atka mackerel by fishing closures. Therefore, while an increase in cod does represent a direct increase in one food source (since SSLs consume cod), it is important to ask, using multispecies analyses and tools, whether the availability of total prey to SSLs will improve if both Atka mackerel and Pacific cod fisheries are reduced.
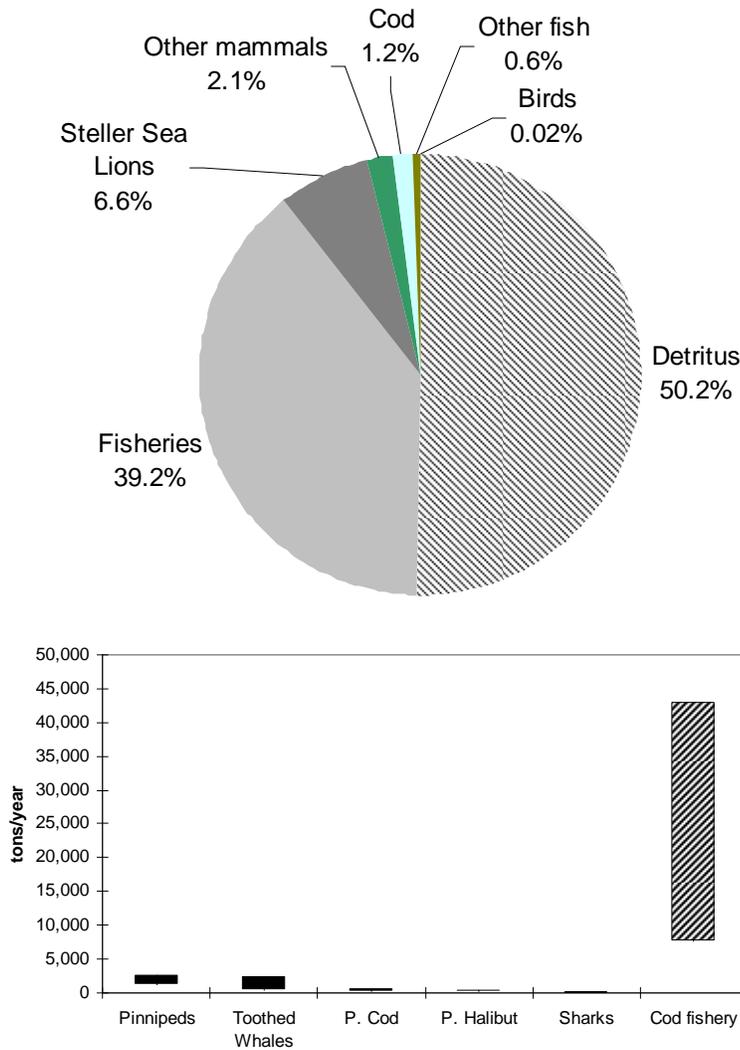
Figure 4. Consumption of Pacific cod ≥20cm fork length by predators (including fisheries) in the Aleutian Islands during the early 1990s as estimated by Aydin et al. (2007). "Consumption" by detritus indicates the difference between total calculated mortality (from stock assessments) and the calculated mortality from accounted predation sources. For a top predator such as Pacific cod, this is assumed to represent death due to senescence. Bottom graph shows credible range of consumption rates (tons/year) as estimated by Aydin et al. (2007). Fisheries range spans the minimum and maximum annual catch for the years 1990-2007. Over 95% of consumption by "pinnipeds" in this figure is attributable to Steller sea lions.

To assess the effects of reducing fisheries on individual species, nonlinear perturbation simulations were run using the EcoSense routines described in Aydin et al. (2007) to simulate changes in the food web and resulting from changing fisheries. To minimize indirect effects between fisheries policies, only changes in mortality of 10% were modeled. Uncertainty runs were completed with a set of 500 feasible ecosystems (out of approximately 50,000 generated by varying both base food web model parameters) to obtain 50% and 95% ranges for resulting perturbations when the models reached equilibrium.

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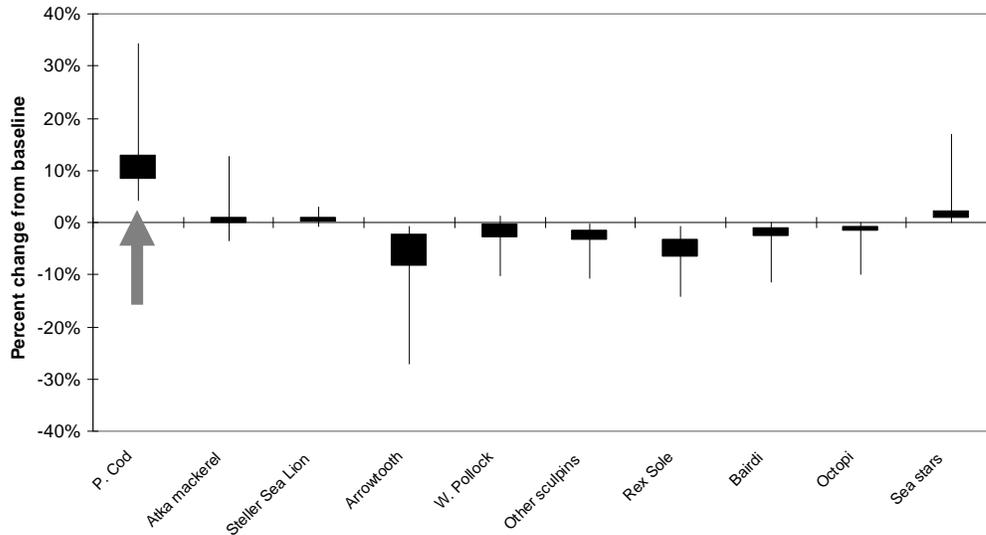
Figure 5. The effects on the Aleutian Islands food web model (percent change of biomass from baseline) of reducing Pacific cod mortality by 10% (manipulated species shown by arrow). Only selected species are shown. Bars and lines show 50% and 95% of results obtained from 500 ecosystems drawn from parameter distributions based on uncertainty in input parameters of biomass, production rates, consumption rates, and diets, as described in Aydin et al. 2007.

The results of reducing Pacific cod mortality in the food web model are shown in Fig. 5. In particular, effects on Atka mackerel and Steller sea lions are extremely limited and uncertain, not clearly changing with the range of responses crossing the baseline. Several prey species of Pacific cod (sculpins and benthic animals) decrease, while lower trophic level benthos such as sea starts are projected to increase, perhaps due to a trophic cascade. Further, there is some evidence of competition, as increasing Pacific cod biomass leads to a decrease in arrowtooth flounder biomass.
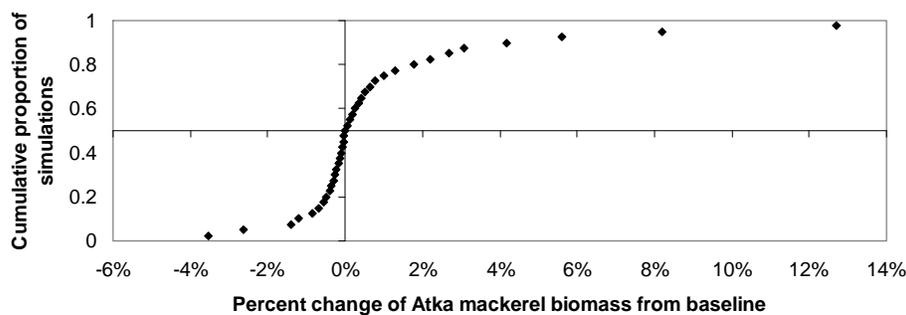
Figure 6. Cumulative proportion of simulations (out of approximately 500) ordered by percent change in baseline of Atka mackerel biomass, under a scenario of an increase in Pacific cod through a 10% reduction in Pacific cod mortality.

Looking in detail at the change in Atka mackerel shown in Fig. 5 shows, in fact, that Atka mackerel in the 500 simulations decreased as often as they increased (Fig 6.), with decreases being due to direct cod predation on mackerel, and the increases perhaps due to increased cod predation on walleye pollock, a competitor with mackerel (see below).

Whether mackerel increases or decreases in this Aleutians-wide increase of Pacific cod thus depends on the relative balance of predation parameters drawn for each simulation.

On the other hand, when Atka mackerel mortality is reduced in a perturbation simulation, a different response is noted (Fig. 7). As Atka mackerel increase, so do Pacific cod and Steller sea lions. However, he greatest interaction is between Atka mackerel and walleye pollock, where an increase in one leads to a decrease in the other. This interaction is both strong and highly uncertain, with a wide range in the results.
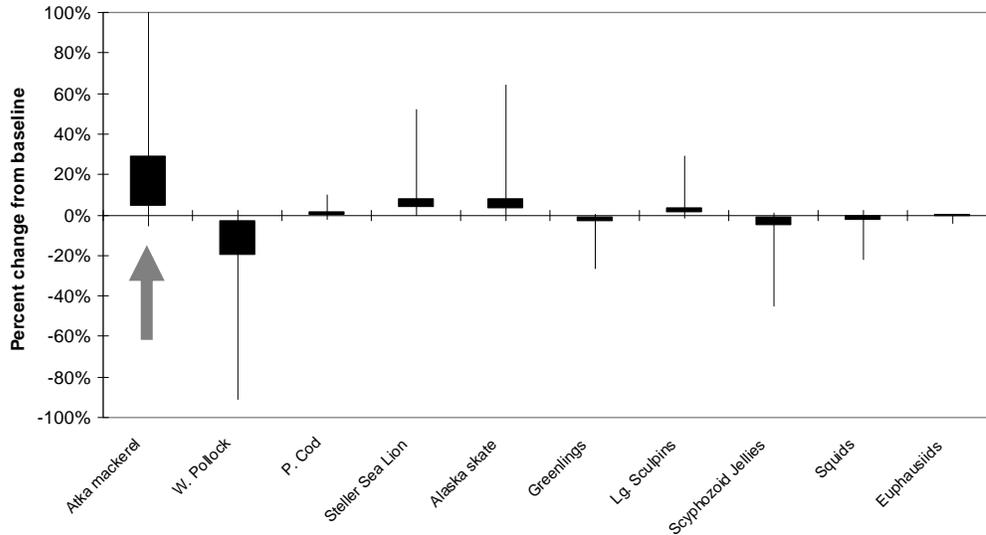
Figure 7. The effects on the Aleutian Islands food web model (percent change of biomass from baseline) of reducing Atka mackerel mortality by 10% (manipulated species shown by arrow). Only selected species are shown. Bars and lines show 50% and 95% of results obtained from 500 ecosystems drawn from parameter distributions based on uncertainty in input parameters of biomass, production rates, consumption rates, and diets, as described in Aydin et al. 2007

This result overall suggests that, in the Aleutian-wide model, competition with pollock has a stronger effect on mackerel than predation by cod. This is explained in part by the size range of Atka mackerel eaten by various predators (Fig. 8, top). Walleye pollock consume primarily smaller mackerel, thus making pollock-caused mortality on mackerel part of a more variable recruitment process rather than a mortality source on adults, as it is with other predators. More importantly, as shown by Fig. 8 (middle and bottom), mackerel and pollock are the main predators of each others' juveniles, in addition to competing for similar sources of food (euphausiids and copepods; diets not shown). An interaction such as this, in a non-spatial model, leads to two species that are tightly connected but with highly uncertain results from their interactions.

In reality, the result of such competition is likely what is actually seen in the Aleutian Islands, as spatial segregation, with pollock higher in the eastern Aleutian Islands and Atka mackerel higher in the west. This, in general, highlights the difficulty of using a nonspatial model to make projections for an archipelago with a huge range of conditions across its longitudinal gradient.
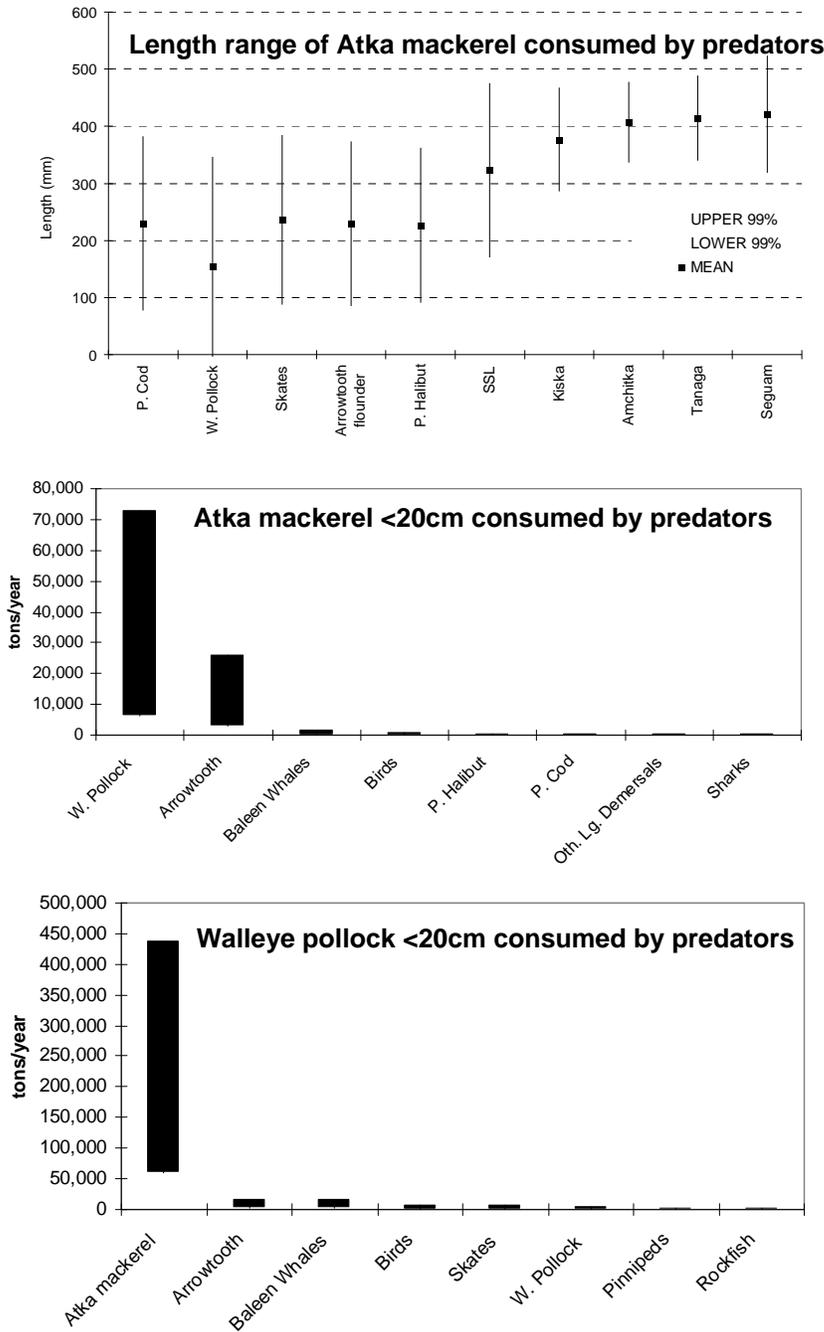
Figure 8.
Top: mean length (mm) and 99% CI of Atka mackerel eaten by predators and included in the biomass estimates at several study sites (from Ortiz and Logerwell 2010). Middle: Consumption of Atka mackerel <20cm fork length by predators in the Aleutian Islands during the early 1990s (Aydin et al. 2007). Bottom: Consumption of walleye pollock <20cm fork length by predators in the Aleutian Islands during the early 1990s (Aydin et al. 2007).

Despite this difficulty, it may be possible to use the model to examine how the effects of spatially-explicit closures might alter the results of this simulation, in particular the results shown in Figs. 5-7. While a spatial simulation model doesn't currently exist,

inferences may be drawn by making a close examination of species and diet trends along the Aleutians.
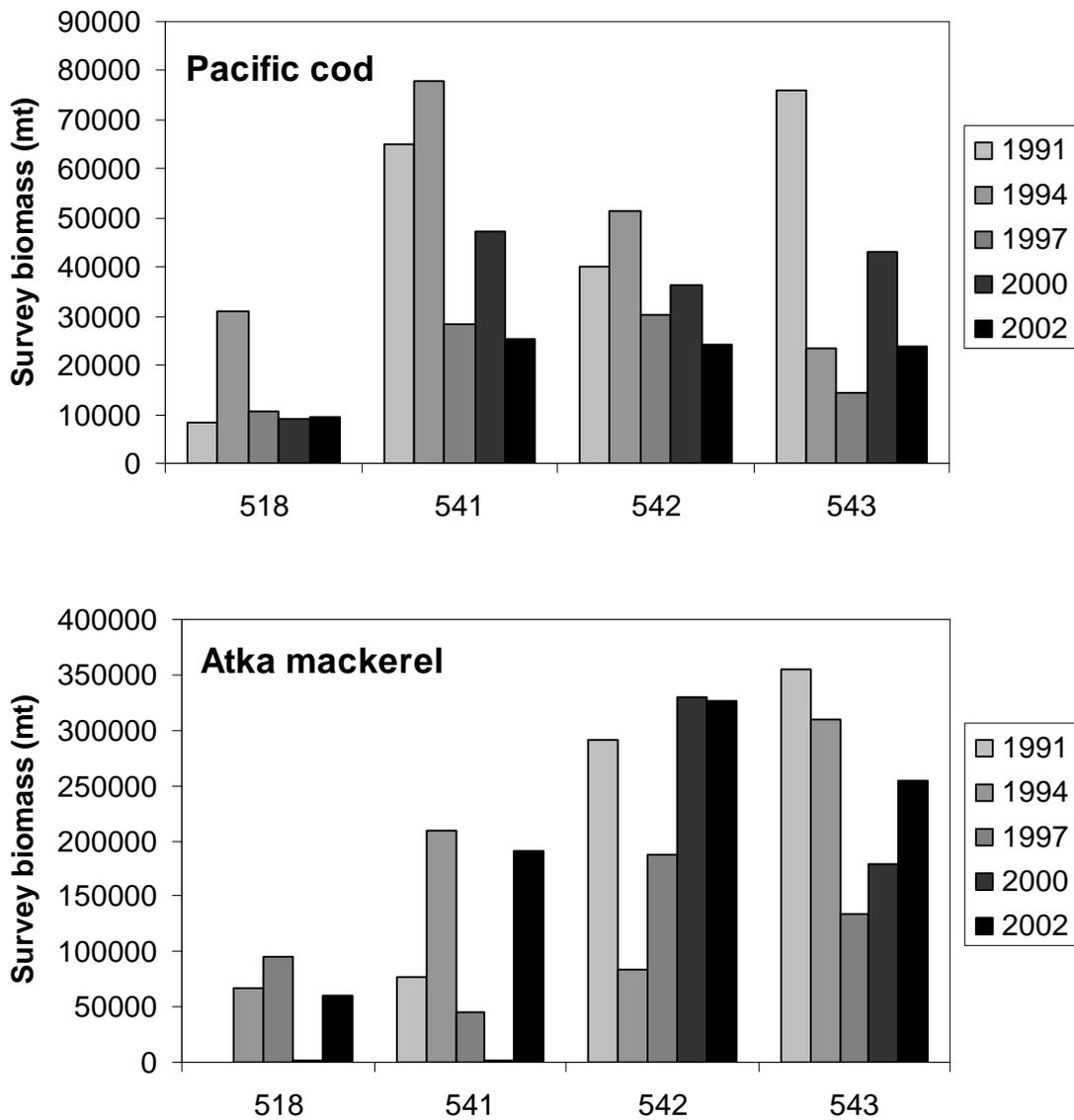
Figure 9. Total biomass (mt) of Pacific cod (top) and Atka mackerel (bottom) as estimated by NMFS Aleutian Island groundfish surveys, 1991-2002.

Fig. 9 shows the groundfish survey biomass of Pacific cod and Atka mackerel. The majority of the Atka mackerel stock is in management areas 542-543, so closures of those areas alone might not be expected to deviate too much from the results shown in Fig. 7 from reduced fishing in the entire Atka mackerel stock. In particular, the result that decreasing fisheries in these subareas would likely lead to increased food supply, and thereafter possible population increases for Pacific cod and Steller sea lions is likely to hold up in a more spatially-explicit multispecies model based on the same data.

However, for Pacific cod, biomass is spread more evenly across areas 541-543 (Fig 9). Further, the spread is not uniform by life stage of cod, nor by cod diet. As shown in Fig. 10, larger Pacific cod (fork lengths between 80-100+cm) tend to be more numerous in the western Aleutian Islands (542-543), while smaller cod are more numerous in the east (541).
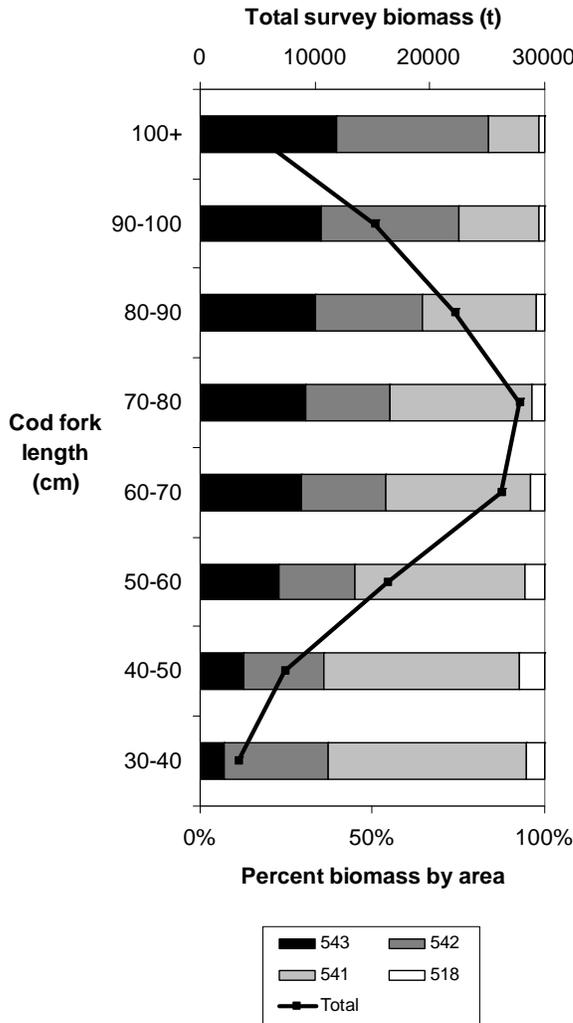
Figure 10. Biomass (mt) of Pacific cod (top) and Atka mackerel (bottom) as estimated by NMFS Aleutian Island groundfish surveys, 1991-2002, by size class across the Aleutians, and as a proportion by management area across the Aleutians.

Pacific cod diet varies by both management area and by size (Fig. 11), with larger cod in 543 consuming the most Atka mackerel by weight of any portion of the cod population. Given the fact that simulations across the whole-Aleutians model of increased cod show a reduction of Atka mackerel in 50% of the simulations (Figs. 5-6) and that reduction of cod fisheries in area 543 would favor the portion of the cod population that feeds most heavily on Atka mackerel, it is reasonable to expect that a spatially-explicit model would

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show a greater proportion of simulations in which Pacific cod increases wouls cause decreases in Atka mackerel. There would therefore be more simulations where decreasing fishing on Pacific cod would have little or no, or even potentially deleterious impacts on increasing prey supply to Steller sea lions.
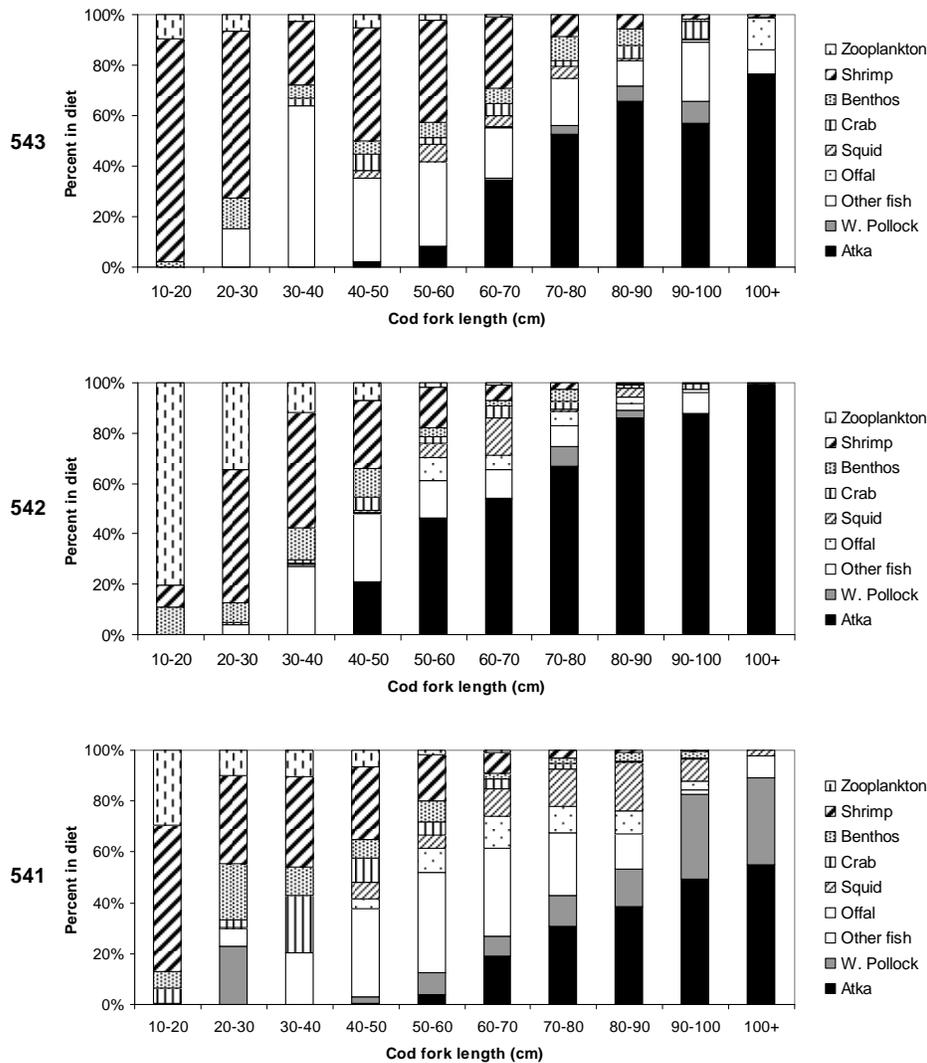
Figure 11. Percent weight in diet of prey items of Pacific cod, by cod fork length and Aleutian Island management region, as sampled from Pacific cod stomachs by Alaska Fisheries Science Center scientists, 1991-2006.

While the food web model used in this analysis does not adequately simulate all details of spatial interactions in the Aleutian Islands, it can give guidance to area closures in conjunction with area-specific data as presented here. Overall, while the model predicts that declines in Atka mackerel fishing would lead to increases in prey supply for Steller sea lions, and that a simulated closure of management area 543 to Atka mackerel fishing would show similar results, the model predictions would be mixed on the results of reducing Pacific cod fishing in area 543, with limited apparent affects on the total Steller sea lion food supply.

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