Evaluating the efficacy of trawl exclusion zones for preserving prey fields of Steller sea lions foraging on Atka mackerel. II. Site specific estimates to evaluate availability of Atka mackerel production for sea lion consumption

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Abstract

Site-specific estimates were developed to examine whether Atka mackerel production inside trawl exclusion zones in 5 local areas in the Aleutian Islands was sufficient to support energetic requirements of Steller sea lions foraging. The sites studied were Seguam Pass, and Tanaga, Amchitka (north/ south) and Kiska Islands. Consumption estimates of Atka mackerel were developed for sea lions and other main fish predators: Pacific cod, Pacific halibut, arrowtooth flounder, walleye pollock and skates. These estimates were compared to Atka mackerel production calculated from mark-recapture model estimates of local Atka mackerel biomass. Results showed geographic variation in the amount of Atka mackerel consumed by predators yet Pacific cod and arrowtooth flounder jointly accounted for at least 50% of the amount consumed regardless of location. Comparing total annual predation of Atka mackerel by fish and sea lions to Atka mackerel production showed that production was sufficient to meet predator demands at Seguam, Tanaga and Kiska, but predation exceeded production at Amchitka. The differences across sites and years in predator biomass and Atka mackerel production showed great variability in the degree to which the amount of Atka mackerel protected within trawl exclusion zones could be expected to meet the energetic demands of Steller sea lions, given the demands of other (fish) predators. In summary, Atka mackerel production in the Seguam Pass trawl exclusion zone greatly exceeded the demands of Steller sea lion consumption. In contrast, the production of Atka mackerel in the Amchitka north trawl exclusion zone probably could not support current or historical foraging needs of Steller sea lions. These results suggest that a "one-size-fits-all" approach to designating protection measures for Steller sea lions may not be effective and factors such as local biomass of prey and competing predators need to be taken into consideration when designing trawl exclusion zones and other marine protected areas.

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Introduction

Steller sea lion (*Eumetopias jubatus*) populations in Alaska declined by more than 80% over the past 30 years (Loughlin, 1998; Loughlin et al., 1992; National Research Council, 2003). The western stock (west of longitude 144° W) was listed as endangered in 1997 under the U.S. Endangered Species Act. The eastern stock, although increasing in size, remains listed as threatened.

Recognizing various direct and indirect interactions between Steller sea lions and fisheries, fishing effort has been spatially and temporally redistributed since 1991 to avoid important sea lion habitat. Most notably, 10-20 nautical mile (nmi) trawl-exclusion zones were established around many rookeries and haulouts to minimize incidental take of sea lions in fisheries, minimize fish removals, and lower the risk of localized depletion of Steller sea lions prey species so as to foster the population's recovery (Angliss and Outlaw 2007, Fritz et al. 1995).

Spatially explicit studies to evaluate fisheries impacts have focused on the effect of local fishing activities around haulouts and rookeries on Steller sea lion population trends (Dillingham et al. 2006, Hennen, 2006). Other studies have examined multiple factors in addition to fisheries activities, affecting each Steller sea lion population (Wolf and Mangel, 2008) inside and outside trawl exclusion zones (TEZ). Potential indirect effects were suggested by Sinclair and Zeppelin (2002), who conducted a study of regional and seasonal dietary differences of Steller sea lions and their overlap with species caught by commercial groundfish fisheries, specifically, walleye pollock (*Theragra chalcogramma*), Atka mackerel (*Pleurogrammus monopterygius*) and Pacific cod (*Gadus macrocephalus*). Sinclair and Zeppelin (2002) noted that in the central and western Aleutian Islands Steller sea lions rely primarily on Atka mackerel year-round. These studies, however, were not designed to evaluate the adequacy of TEZs to fulfill the objectives for which they were implemented. To fill this gap, McDermott et al. (this volume) estimated local abundance and movement of Atka mackerel inside and outside of TEZs in the Aleutian Islands.

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Atka mackerel is not only the major commercially caught species in this region, it is also an important prey species for several groundfish. Based on a food web model developed by Aydin et al. (2007) for the Aleutians Islands, Atka mackerel are consumed primarily by Steller sea lions, Pacific cod, walleye pollock, arrowtooth flounder (*Atheresthes stomias*), Pacific halibut (*Hippoglossus stenolepis*), and skates (*Bathyraja* spp.) in addition to being fished by commercial fisheries (Figure 1). Other studies have shown that there are longitudinal gradients both in biomass and feeding habits along the Aleutian Islands that result in distinct food-webs (Logerwell et al. 2005 and Ortiz 2007). This study incorporates the local population estimates by McDermott et al. (this volume) and the estimated predation on Atka mackerel at those specific TEZs by the 5 main Atka mackerel groundfish predators and Steller sea lions. These numbers were then used to evaluate whether there is enough Atka mackerel production inside Trawl Exclusion Zones (TEZs) to support Steller sea lion energy needs for current population numbers and for historic population numbers before the Steller sea lion population decline.

Methods

Study site

We estimated predation on Atka mackerel at 5 study sites in the Aleutian Islands Archipelago, each site encompasses one or more Trawl Exclusion Zone (Figure 2). The study sites correspond to the tag, release, and recovery locations for Atka mackerel from McDermott et al. (this volume) and are year specific based on the year of tagging (Figure 3). The sites are each enclosed in an area of 3-degrees-of-longitude to estimate predator density and diet (see details below):

Seguam Pass 2002: encompasses 1 TEZ within 172ºW and 175ºW.

Tanaga Pass 2002: includes 3 TEZs within 177ºW and 180ºW

Amchitka Island, north site 2003: includes 2 TEZs within 177ºE and 180ºW

Amchitka Island, south site 2003: includes 3 TEZs within 177ºE and 180ºW

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Kiska Island 2006: covers 2 overlapping TEZs within 177ºE and 180ºW

Data

Table 1 summarizes the data used, the sample size and the data source. Annual production and consumption rates were calculated for the specific year for which Atka mackerel biomass was calculated.

Atka mackerel

Atka mackerel biomass inside the TEZs at each site was taken from McDermott et al. (this volume) who used a mark-recapture model to estimate biomass both inside and outside the TEZs at each site.

The production per unit of biomass (*P/B*) of Atka mackerel for any given year *y* can be approximated as:

$$\left(P/B\right)_y = \frac{\sum_{a=0}^{a=11} \hat{N}_{a,y} * \Delta \hat{W}_a}{\sum_{a=3}^{a=11} \hat{N}_{a,y} * \hat{W}_a} \qquad (1)$$

where $\hat{N}_{a,y}$ are the year specific estimated number at age, $\hat{W}_a$ is the estimated weight at age,

We used weight-at-age data specific for the Aleutian Islands; year specific number-at-age estimates used to scale individual weights to population-level were taken from the 2008 stock assessment for Atka mackerel (Lowe et al. 2008). Because the stock assessment has estimated numbers starting at age 1, we estimated the predation mortality of age zero and age one.

Steller sea lions

Abundance: Year specific numbers at age of Steller sea lions at each study site were estimated using a state-space model based on the Kalman filter. The model allowed for movement across rookeries (Gavin Fay, pers. comm.).

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The rookeries and haulouts selected for this study comprised approximately 50% of the total population in the central Aleutian Islands. Table 2 and Figure 3 show the specific rookeries/ haulouts included in each site.

Biomass: Age-structure of the population was considered to be the same at all sites and years and was calculated by updating York's (1994) age structure with Holmes et al (2007) scaling factor. The sex ratio of the populations was also considered the same at all sites and years and was calculated using sex-age specific survival rates derived from a study at Marmot Island (Gulf of Alaska) using mark recapture data (Lowell Fritz, pers. comm.). Average weight at age for combined sexes was calculated by averaging non-pregnant female, pregnant female, and male weight at age, weighted by sex ratio, birth proportion at age and age structure. The year specific biomass at each site was estimated by multiplying the numbers at age by the weighted average weight at age for males and females combined.

Diet composition was based on site specific scat collections during 1990-1999 taken from the National Marine Mammal Laboratory (NMML) diet database for Steller sea lion. We used scats collected at rookeries or haulouts near the population count locations at each study site to estimate frequency of occurrence (Figure 3).

Consumption rate (Q/B) was taken from Aydin et al (2007) who scaled the average individual body weights and daily caloric requirements listed in Hunt et al. (2000) to an annual rate.

Historical comparison: Sea lion biomass at each site was also estimated for 1977, when sea lion numbers were still relatively high. The purpose of this "historical" estimate of sea lion abundance (and consumption) was to examine whether Atka mackerel production in TEZs would be sufficient to maintain sea lions at historically higher levels. Because no sea lion diet data from the central Aleutians were collected during the 1970s or 1980s, the same diet and consumption rate estimates were used to calculate "historical" as well as year-specific sea lion consumption of Atka mackerel.

Fish predators

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Fish predators include Pacific cod, walleye pollock, arrowtooth flounder, Pacific halibut, and skates. The Alaska Fisheries Science Center (AFSC) of the National Marine Fisheries Service (NMFS) conducts biennial standardized bottom trawl surveys to collect data on the distribution, abundance, population structure, and feeding habits of Alaska groundfish stocks. The surveys in the Aleutian Islands cover depths down to 500 m and employ a stratified random sampling. There are 50 strata covering the Aleutian Island region which are both geographically (Eastern, Western, Central north/south) and depth defined (<100m, 100-200m, 200-300m, 300-500m). Both haul-by-haul catch-per-unit-effort (CPUE) and biomass estimates by survey strata are available from the Resource Assessment and Conservation Engineering (RACE) Database. The AFSC conducted surveys in 1980, 1983, 1986, 1991, 1994, 1997, 2000, 2002, 2004, and 2006.

Biomass estimates at each site were based on survey estimates for the corresponding year for which Atka mackerel biomass was estimated, except for 2003 when there was no survey and we used 2004 data. In order to downscale survey strata biomass estimates to biomass within each TEZ, we first proportioned the corresponding individual stratum biomass to the 3 degree areas of each study site based on the CPUE of hauls falling within the 3 degree areas. We then assumed a homogeneous density for each stratum within the 3 degree area and applied it to the stratum area in the TEZs at each study site. We summed across strata to get the biomass estimates within the TEZs .

$$B_{3\deg reestratum,y} = B_{stratum,y} * \frac{\sum CPUE_{stratum,y} in 3\deg reearea}{\sum CPUE_{stratum,y}} \quad (2)$$

$$B_{TEZ,y} = \sum_{strata} Area_{TEZstratum} * \frac{B_{3\deg reestratum,y}}{Area_{3\deg reestartum}} \quad (3)$$

We did not proportion the survey strata biomass directly to the TEZs because areas along the passes are hard to trawl, potentially underestimating the biomass based directly on

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proportioning CPUEs of hauls inside the TEZs. Figure 3 shows the survey strata and the TEZ areas to which the biomass estimates were downscaled.

Diets: for all the fish predators we selected stomach samples falling within the 3 degree areas of each study site to allow for suitable sample sizes for all predators. From these samples we calculated the proportion by weight of Atka mackerel with respect to all other prey items. Diets for fish were based on stomachs collected between 2000 and 2006, except for skates for which we used samples from 1997 to 2006 to increase the sample size. We did not weight the diet estimates by age structure as there were not enough stomach samples per year to allow for age specific diets.

Consumption rates were estimated as $(H/A)\cdot W_t^d$ where A is assimilation efficiency, H is an assimilation constant and weight at age was calculated as:

$$W_t = W_\infty \bullet \left(1 - e^{-k((1-d)(t-t_0))}\right)^{\frac{1}{1-d}} \qquad (4)$$

where W_∞ (asymptotic body mass) is $(H/k)^{\frac{1}{1-d}}$, k is an energy loss constant, d is the allometric slope of consumption, t_0 is the age when $W=0$ weight at time zero; respiration linearly proportional to body weight (Essington et al. (2001).

Equation 4 was fit to weight-at-age data for pollock specific to the Aleutian Islands, for Pacific cod we fitted to Aleutian Islands/Bering Sea data and for arrowtooth flounder we fit to Gulf of Alaska data. Method details for estimating consumption rate are described in Essington et al. (2001). Individual consumption was scaled to population-level consumption using the available year specific numbers-at-age data from the 2008 stock assessments for walleye pollock, Pacific cod and arrowtooth flounder (Barbeaux et al. 2008, Thompson et al. 2008, Turnock et al. 2008). For skates and halibut we assumed a consumption rate of 2.0 and 1.1 respectively as estimated by Aydin et al. (2007).

Estimates of Atka mackerel consumed

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We estimated the amount of Atka mackerel consumed at each study site from the shelf area down to 500m depth. The estimates are considered annual as both consumption and production rates were scaled to yearly totals. Although we used year-round samples to estimate the proportion of Atka mackerel in the predator's diets, sampling occurred mainly in the summer (May-September) –when it is assumed most of the consumption takes place. Fish and Steller sea lion biomass estimates are based on summer surveys as well.

The total year specific consumption of Atka mackerel by predators was estimated as:

$$\text{Total Atka mackerel consumed}_{y} = \sum_{j}\left[B_{j,y,s} * \left(\frac{Q}{B}\right)_{j,y} * DC_{Atkamackerel,j,s} \right] \qquad (5)$$

Where y is the year 2002, 2003 or 2006 depending on the site, $B_{j,y,s}$ is predator j biomass in tons during year y at site s, $QB_{j,y}$ is the annual consumption rate of predator j in year y, and $DC_{Atkamackerel,j,s}$ is the percent by weight of Atka mackerel in a predator's j diet at site s.

Total production is the product of the year specific production rate and year/site specific biomass of Atka mackerel:

$$\text{Production y,s} = PB_{y,s} * B_{y,s} \qquad (6)$$

We used the production estimate only to evaluate whether the estimated consumption by all predators inside the TEZ could be satisfied by the local production. We used the median, 5th and 95th quantiles of the biomass estimates to provide a range of production estimates.

Results

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The parameters used in the Von Bertalanffy equation to estimate PB and QB are sshown in Table 3. The resulting biomass, production and consumption estimates used to estimate the amount of Atka mackerel consumed at each site are presented in Table 4.

Consumption of Atka mackerel

The contribution of Atka mackerel to fish and sea lion diets is shown in Figure 4. Figure 5 shows predator biomass and total Atka mackerel consumed at each site. Atka mackerel is a primary prey of arrowtooth flounder, skates and Pacific cod (up to 88% of their diet). However, depending on their biomass, the amount of Atka mackerel these predators consume may only account for a small proportion of the total Atka mackerel biomass consumed at a given site. Such is the case of skates, whose consumption of Atka mackerel diet makes up less than 10% of the total Atka mackerel consumed at any study site, despite a percent weight of Atka mackerel of 75% in their diet. Conversely, predators whose diet may include only a small proportion of Atka mackerel may account for a large portion of the total Atka mackerel consumed if their biomass is high, as is the case for pollock.

The largest biomass of Atka mackerel predators is estimated at the Tanaga and Seguam study sites. These sites have the largest biomasses of both Steller sea lions, pollock and arrowtooth flounder. Across all sites, Pacific cod and arrowtooth flounder combined account for at least 50% of the Atka mackerel consumed.

Atka mackerel production

Production estimates of Atka mackerel seem to satisfy local consumption in most sites, except for Amchitka North where the estimated consumption exceeded production (Figure 6). Substituting the current Steller sea lion biomass with their biomass in 1977 when the populations were healthy shows consumption would almost match production at Kiska, Amchitka South and Tanaga while considerably exceeding production at Amchitka North.

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Discussion

Groundfish and sea lions consume Atka mackerel of up to 45cm in length, with considerable overlap of length classes consumed by all predators (Figure 7). Our site specific estimates for a suite of trawl exclusion zones (TEZs) in the Aleutian Islands showed that Atka mackerel production varied geographically and for some locations and scenarios (i.e., historical sea lion population sizes) may not be sufficient to sustain the combined foraging needs of Steller sea lions and groundfish predators, We recognize these production estimates are very conservative and show the production range for any given site based on the upper 95% and lower 5% year/site specific biomass estimates for Atka mackerel from McDermott et al. (this volume) (Figure 8a).

The biomass estimates we used for Atka mackerel are not age structured, and include only individuals of length 30cm and longer because this is the lower size limit of fish tagged in McDermott et al. (this volume). Because there are no actual estimates of recruitment of young fish into the adult population but small Atka mackerel were frequently consumed by predators, we consider some adjusted biomass estimates that incorporated young fish (smaller than 30 cm). From the Atka mackerel age structure estimated in the stock assessment and extended to include age 0, we calculated that ages 0-2 (those less than 30cm) accounted for a maximum of 45% of total biomass in the years studied, and increased the biomass estimates from McDermott et al. accordingly. Even assuming all juveniles stayed within the TEZ, the production ranges based on the adjusted biomass may still not be sufficient to support the estimated consumption in all locations (Figure 8b).

To address changes in production rates, we show a corrected high production estimate, based on increased abundance and production rates. Since production rates are highly dependent on the age structure of the population, we calculated the corresponding production rates for all years included in the stock assessment and applied the highest value (1.23) to the increased (+45%) biomass estimates. Even under this corrected high production scenario the Amchitka North area is still at risk of falling short of production to satisfy consumption by predators (Figure 8c).

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The best estimates for Steller sea lion vital rates are based on data collected in the central Gulf of Alaska (York 1994; Holmes et al 2007). Vital rate information from the Aleutian Islands sea lions was not available for the construction of this model and therefore we used data from the central Gulf of Alaska. Aerial survey photographs taken in 2004 indicated similar age structures of Steller sea lions between the central Gulf of Alaska and the Aleutian Islands (L. Fritz, NMML, pers. com.), supporting the use of Gulf of Alaska vital rate estimates of Steller sea lions in our Aleutian Islands model.

An independent estimate of Steller sea lion consumption rates compared favorably with ours. Winship et al. (2002) built a bioenergetic model to estimate food requirements of Steller sea lions in Alaska. Using their estimates of daily food requirements applied to the age structure and number of individuals in our study sites yielded consumption estimates similar to ours (Table 5).

We constructed annual food-web models to examine the geographic patterns in Atka mackerel production and consumption by predators. by scaling both growth and consumption rates to yearly totals. Much of the field data used to build the model were collected during the summer, however it was assumed that most of the consumption occurs during the summer. The summer estimates of Atka mackerel biomass are expected to be a fair representation of local biomass throughout the year. Tag release and recovery data over multiple years indicate that there is little movement of fish among our study sites (McDermott, AFSC, pers. com.)

The TEZ were established with the aim of ensuring availability of adequate food resources to Steller sea lions, decreasing competition with fisheries and promoting their recovery. This study determined that the estimates of total consumption by groundfish and sea lions can both exceed the estimated local production of Atka mackerel, or be well below it, depending on the site. Leaving other prey items aside, the mismatch between production and consumption can be interpreted as a mismatch in adequate size of the TEZ surrounding rookeries and haulouts. In the case of Amchitka North, the TEZ would

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either have to be extended or combined with other measures in the vicinity of the TEZ to ensure enough Atka mackerel are available to sea lions without competition from fisheries. Conversely, some TEZ and the management measures in their vicinity could be revised to allow larger catches. This would seem to be the case of Seguam, where estimated production exceeds consumption even at high population levels of Steller sea lions. In revising management measures and TEZs, we note that ensuring production is not the only or ultimate goal of a TEZ. Reduced competition with fisheries as well as conservation of preferred foraging grounds are also important. Atka mackerel spawining grounds may comprise preferred foraging grounds for Steller sea lions (Lauth et al., 2007) which degrade as a consequence of fishing impacts (Cooper et. al. this volume). We recognize establishing colony-specific sizes of TEZs and other management measures may be a time consuming process, and propose this as a tool to evaluate and refine TEZ efficacy after they have been implemented. Matching TEZs or protected areas along with other management measures to the local condition of endangered or threatened populations can better serve both conservation goals and fisheries interests.

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Table 1. Summary of year specific sample sizes and data available for each site.

Data	Sample size		Source
Survey strata biomass	94 – 147 hauls		AFSC
3-degree area CPUE	60 – 87 hauls		AFSC
Fish stomach samples at each 3-degree area pooled for 2000-2006 (1997-2006 for skates)	Pollock	204-349	AFSC
	Arrowtooth Flounder	163-391	
	Halibut	33-115	
	Pacific cod	204-393	
	Skates	26-78	
Atka mackerel biomass	7,918 – 24,999 tagged fish released		McDermott
	46 – 769 tagged fish recovered		
Steller sea lion biomass	1 – 12 sites		Gavin Fay* pers. comm, Holmes 2007, York 1994, Fritz (pers. comm..NMML)
Steller sea lion diet (1990-1999)	220 – 297 scats		NMML

*Gavin Fay, (CSIRO, Australia)

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417 Table 2. Rookeries and haulouts of Steller sea lion included in each study site

Site	Haulout/Rookery
Seguam	Seguam/ Saddleridge
Seguam	Seguam/ Finch Point
Seguam	Agligadak
Seguam	Amlia/ East Cape
Seguam	Sagigik
Seguam	Amlia/ Sviech. Harbor
Seguam	Amlia/ Cape Misty
Seguam	Tanadak (Amlia)
Seguam	Seguam/ Lava Point
Seguam	Seguam/ SW Rip
Seguam	Seguam/ Turf Point
Seguam	Seguam/ Wharf Point
Tanaga	Tag
Tanaga	Ugidak
Tanaga	Gramp Rock
Tanaga	Kavalga
Tanaga	Unalga/ Dinkum Rocks
Tanaga	Ilak
Tanaga	Tanaga. Cape Sasmik
Amchitka S	Amchitka/ East Cape
Amchitka S	Amchitka/ Chitka Point
Amchitka N	Ayugadak
Amchitka N	Rat
Amchitka N	Amchitka/ Column Rock
Kiska	Kiska/ Lief Cove
Kiska	Kiska/ Cape St. Stephen
Kiska	Kiska/ Sobaka-Vega
Kiska	Kiska/ Witchcraft Point
Kiska	Kiska/ Pillar Rock

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Table 3. Parameters values used in Von Bertalanffy equation

$W_t = W_\infty * (1 - \exp(-k(1-d)(t - t_0)))^{\frac{1}{1-d}}$ with d set at 0.8

	W_∞	k	t_0
Atka mackerel	800.29	3.17	-0.95
Walleye pollock	1038.9	2.41	-0.66
Pacific cod	16507.14	0.90	-0.99
Arrowtooth flounder	1209.52	1.34	-1.12

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Table 4. Year/site specific estimates used in model to calculate total amount of Atka mackerel consumed. Biomass and amount eaten are in tons, QB is shown for all except Atka mackerel (Am) and is in tons consumed per ton of biomass, PB is shown for Atka mackerel, tons produced per ton of biomass.

	Skates	Arrowtooth flounder	P. Cod	P. Halibut	W. Pollock	Steller sea lion	Atka mackerel
Seguam 2002							
Biomass	4,336	7,941	2,742	2,593	24,207	284	273,452
Atka eaten	4	4,596	3,474	980	2,405	3,606	
% Atka in diet	0.1	21.1	57.3	34.4	2.2	52.7	
QB or PB	2.0	2.7	2.2	1.1	4.5	24.0	0.5
Tanaga 2002							
Biomass	908	2,839	3,147	972	20,812	254	73,702
Atka eaten	1,361	6,852	5,358	597	6,273	3,291	
% Atka in diet	75.0	88.0	77.0	55.8	6.7	53.8	
QB or PB	2.0	2.7	2.2	1.1	4.5	24.0	0.5
Amchitka N 2003							
Biomass	307	2,718	2,861	527	822	81	14,695
Atka eaten	334	6,092	4,255	111	0	792	
% Atka in diet	54.3	81.9	68.2	19.2	0.0	40.7	
QB or PB	2.0	2.7	2.2	1.1	4.5	24.0	0.5
Amchitka S 2003							
Biomass	68	526	749	140	137	31	10,099
Atka eaten	74	1,179	1,113	30	0	305	
% Atka in diet	54.3	81.9	68.2	19.2	0.0	40.7	
QB or PB	2.0	2.7	2.2	1.1	4.5	24.0	0.5
Kiska 2006							
Biomass	618	499	2,142	521	1,169	119	59,658
Atka eaten	671	1,090	3,068	110	0	1,162	
% Atka in diet	54.3	81.9	68.2	19.2	0.0	40.7	
QB or PB	2.0	2.7	2.1	1.1	4.5	24.0	0.6

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Table 5. Annual consumption (tons/year) estimates for Steller sea lions from our small-scale food web model and derived from Winship et al (2002) daily estimates by age.

Study site	Food web model (this paper) (t/y)	Winship et al (2002) (t/y)
Kiska	1162	1304
Amchitka N	792	888
Amchitka S	305	342
Tanaga	3291	3692
Seguam	3606	4046

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Figure 1. Consumption of Atka mackerel by predators in the Aleutian Islands during the early 1990s as estimated by Aydin et al (2007).

Figure 2. Location of study sites in the Aleutian Islands Archipelago.

Figure 3. Individual study sites: top panel Seguam Pass, middle Tanaga Pass, bottom Kiska, Amchitka North, and Amchitka South.

Figure 4. Contribution of Atka mackerel to fish diets (in percent by weight) and Steller sea lions (SSL) diets in frequency of occurrence (FO).

Figure 5. Estimated biomass of each predator (circle diameter proportional to biomass) and estimated consumption (bars) by predator at each study site. Results are year year specific: Kiska, 2006; Amchitka North and South, 2003; Tanaga and Seguam, 2002.

Figure 6. Year specific local production of Atka mackerel vs. consumption of Atka mackerel by main predators top panel: Kiska, 2006; Amchitka 2003; Tanaga 2002; Seguam, 2002. Bottom panel shows total local consumption as estimated when using the consumption by Steller sea lions biomass levels of 1977. Atka mackerel production at Seguam was off the chart, at 136,726 metric tons.

Figure 7. Mean length (mm) and 99% CI of Atka mackerel eaten by predators and included in the biomass estimates at each study site (data for fish from AFSC feeding habits database, length at size Susan McDermott pers. comm., prey size for Steller sea lions from Zeppelin et al. 2005).

Figure 8a, b and c. Range of estimated production based on biomass estimates. Bars denote consumption, Lines show Atka mackerel production estimated using the year specific age structure applied to the upper 95%, lower 5% and median biomass. Top plot shows production estimate based on abundance of fish >30 cm. Middle plot shows production estimates based on adjusted biomass (+45%) to account for fish <30 cm. Bottom plot shows production estimate based on the highest production rate estimated from all years in stock assessment (1977-2008) and adjusted biomass.

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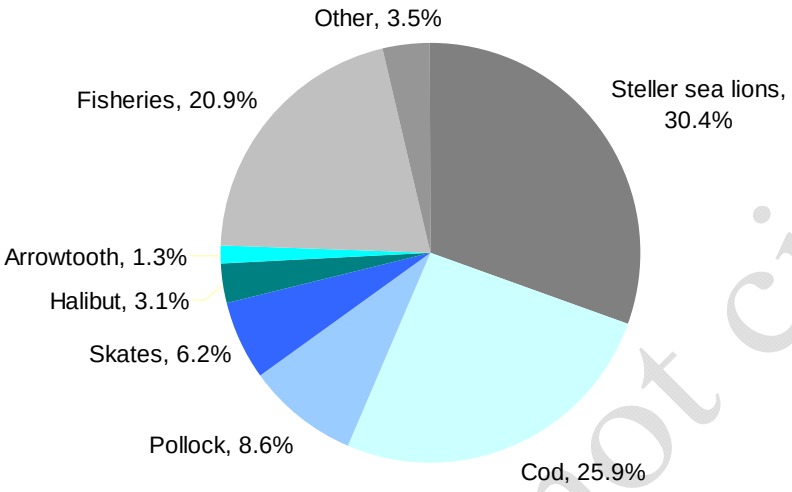

Figure 1.

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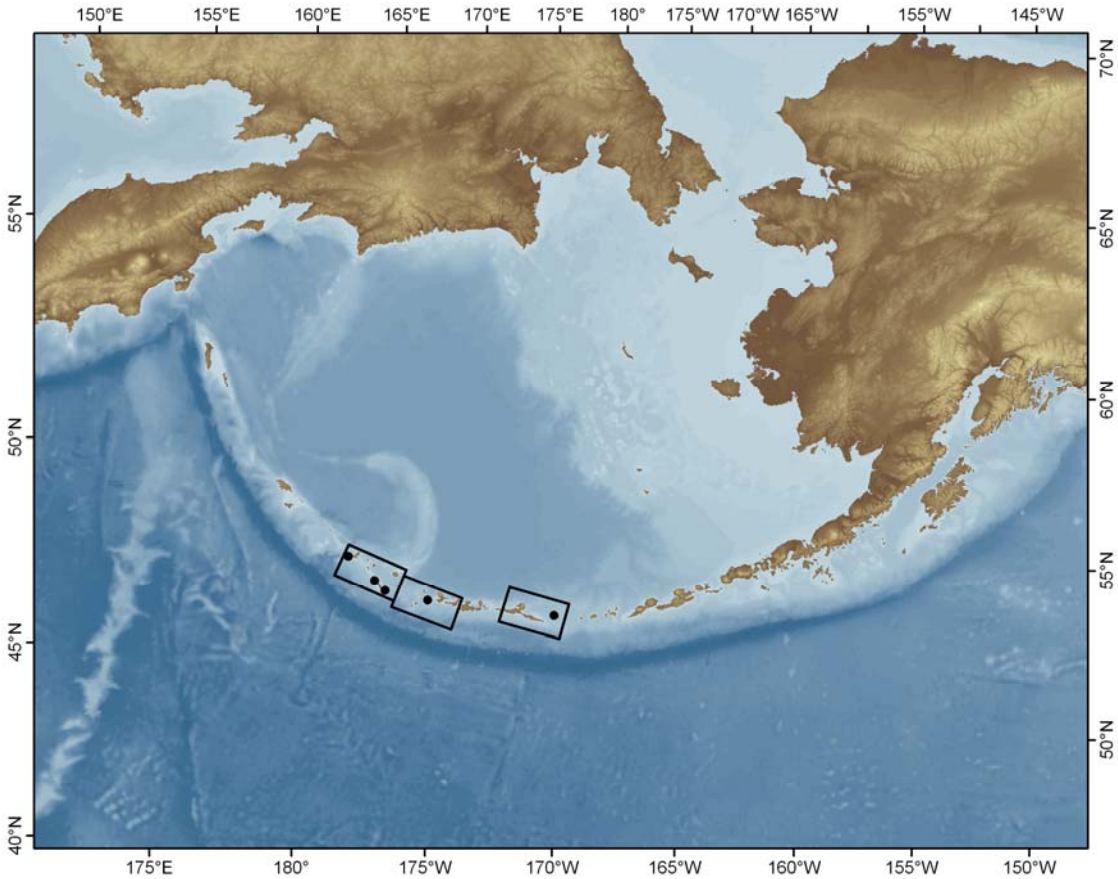

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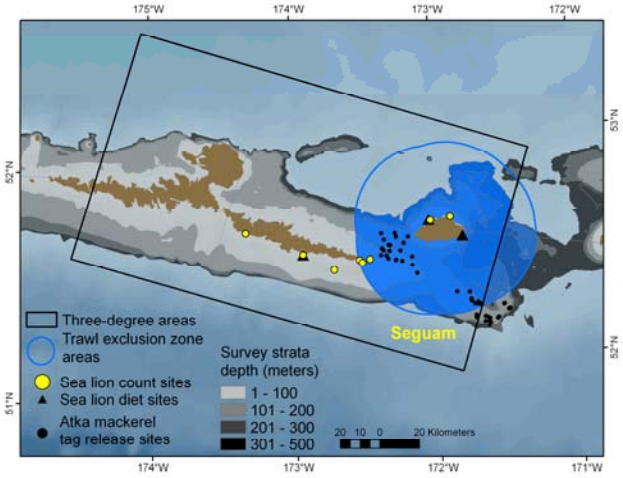

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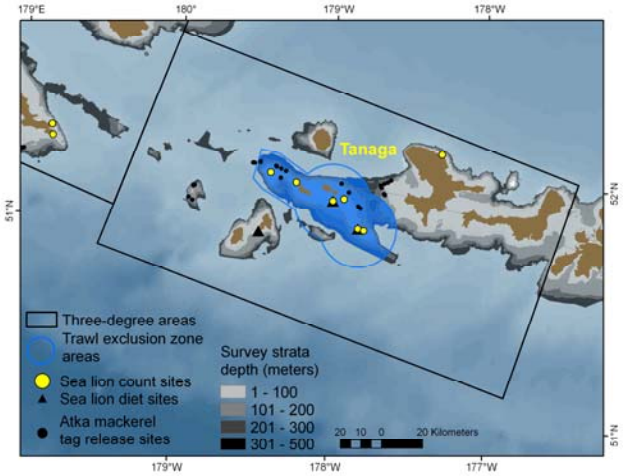

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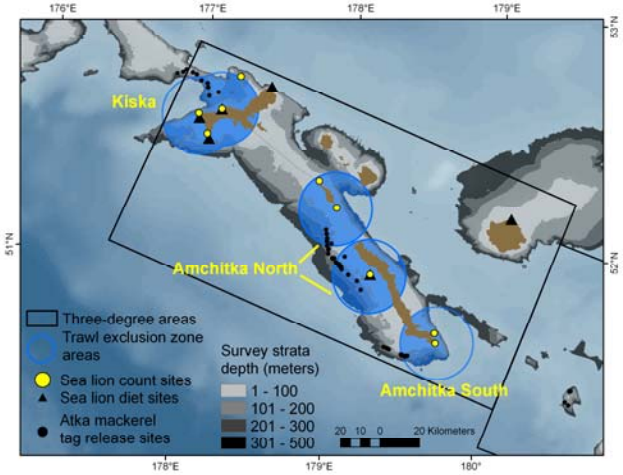

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461 Figure 3.

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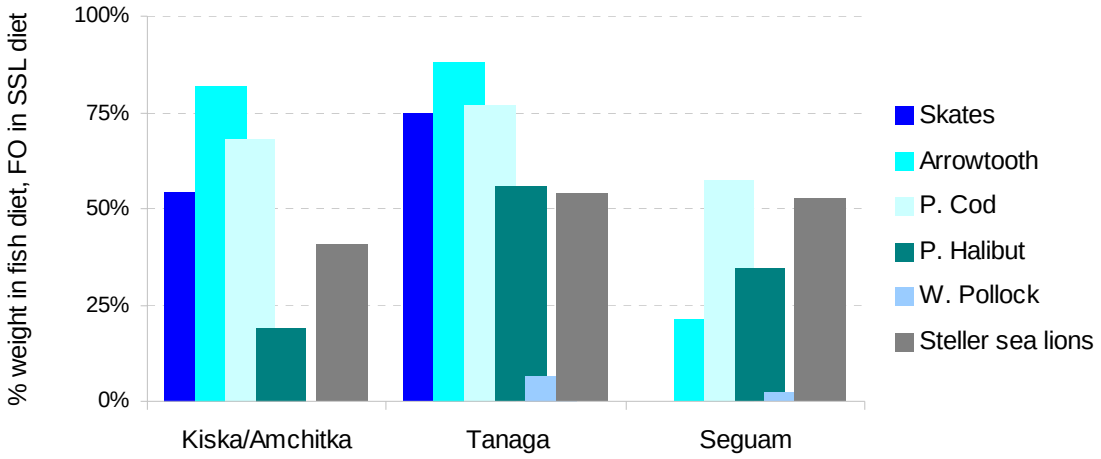

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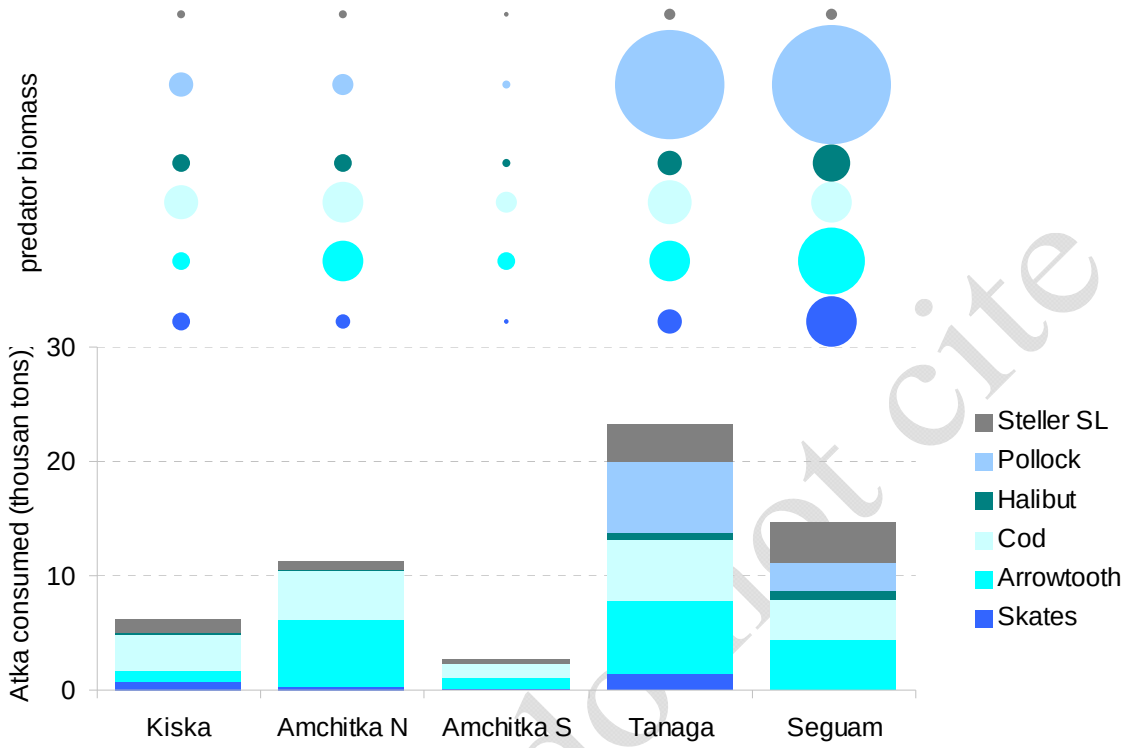

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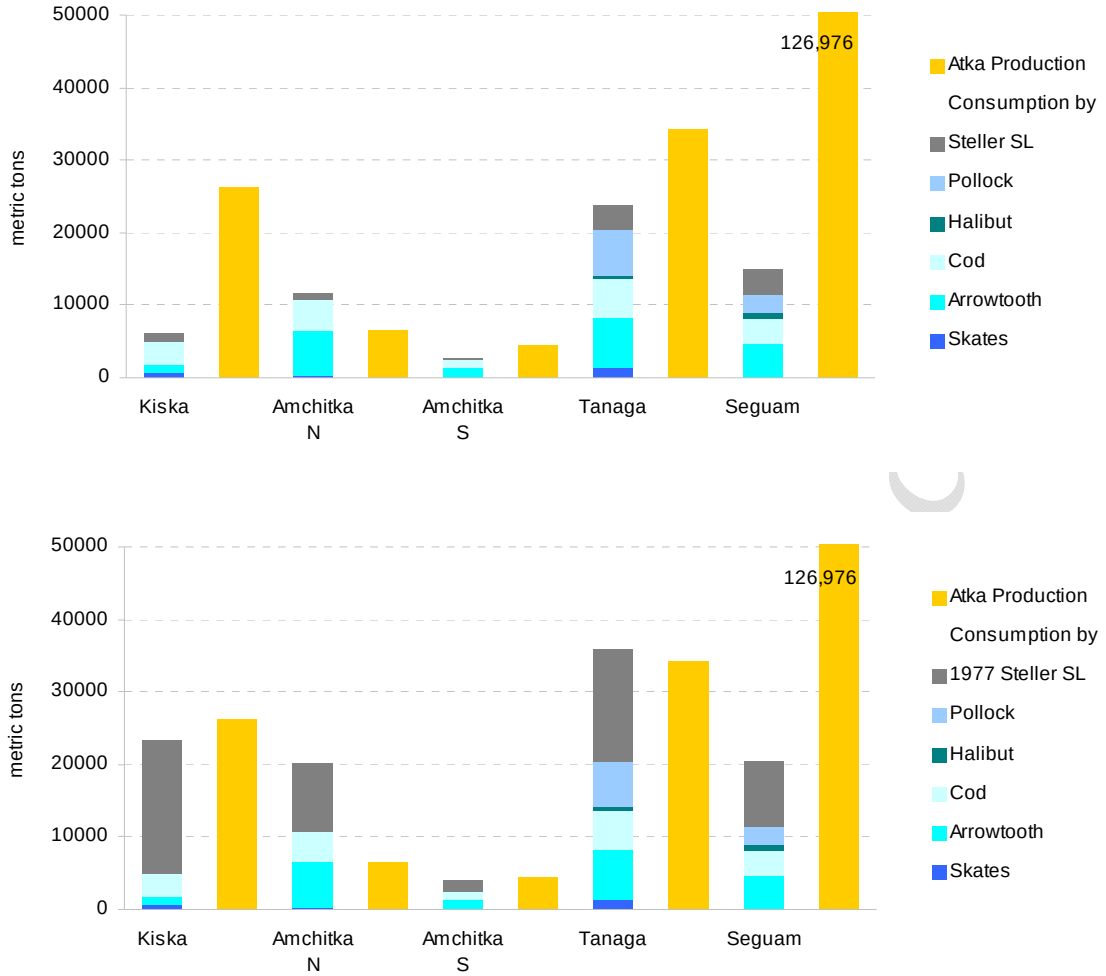

Figure 6.

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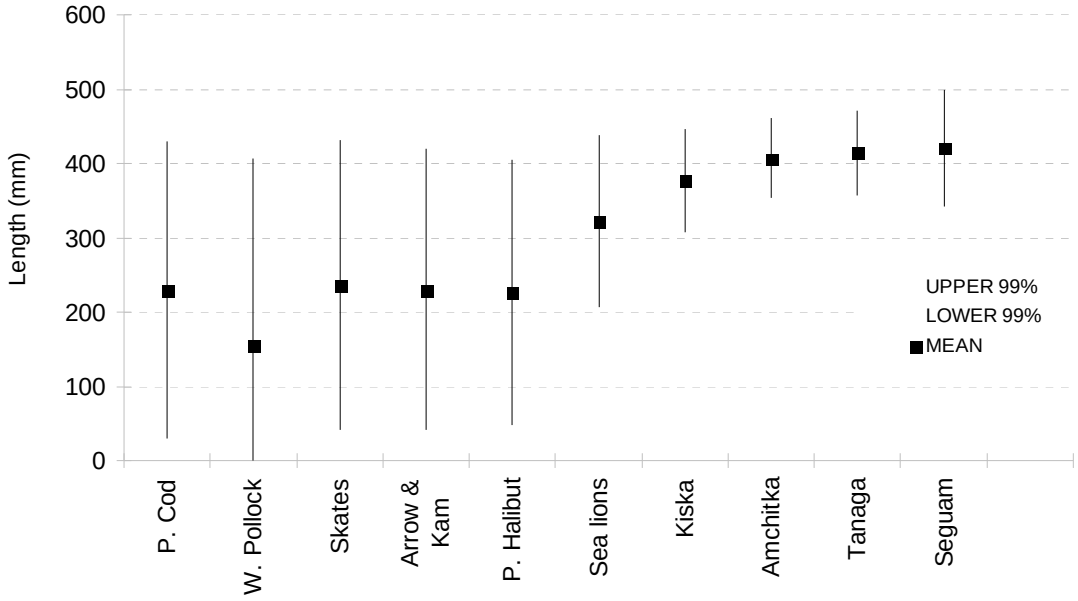

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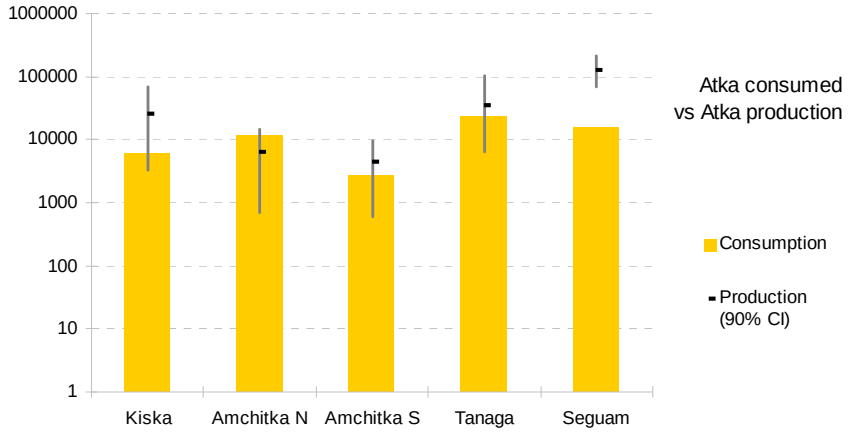
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Amchitka S
Tanaga
Seguam
Atka consumed
vs Atka production
Consumption
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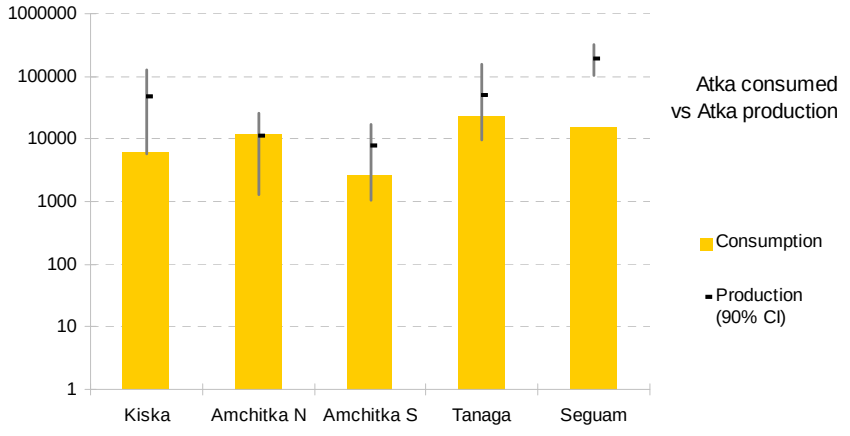
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Atka consumed
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Production
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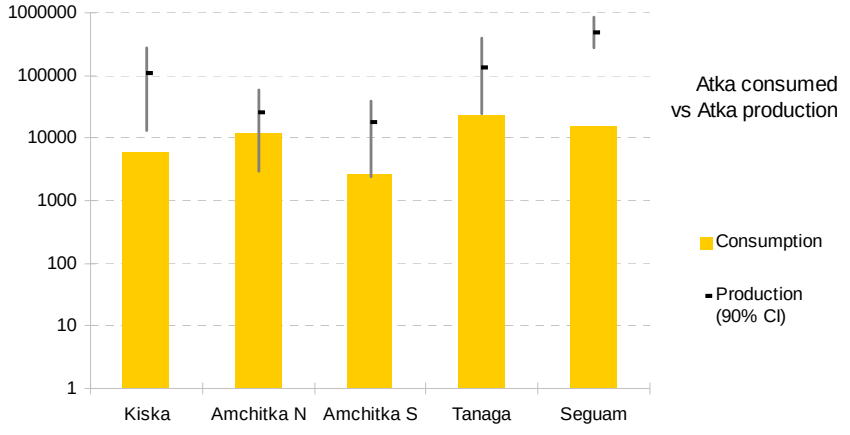
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Tanaga
Seguam
Atka consumed
vs Atka production
Consumption
Production
(90% CI)

Figure 8a, b, c.