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Estimation of Hawaiian Monk Seal Consumption in Relation to Ecosystem Biomass and Overlap with Fisheries in the Main Hawaiian Islands

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EXECUTIVE SUMMARY

As the Hawaiian monk seal population has recently increased in the main Hawaiian Islands, it has resulted in increased marine resource use overlap between monk seals and commercial, recreational, and subsistence fisheries. This has understandably led to questions and concerns about the potential impact of Hawaiian monk seals on the near shore ecosystem and in particular, on populations of marine species that are consumed by humans. In this analysis, we estimated food consumption by the current Hawaiian monk seal population in the main Hawaiian Islands. To put this consumption into context, we also estimated biomass of near-shore fishes, including apex predators, herbivores, secondary consumers, and planktivores, and the biomass consumption by apex fish predators and humans (i.e., fishery landings). Finally, we compared the families of fish found in the monk seal diet and those targeted by fisheries.

Major findings:

- We estimate that the current population of about 200 Hawaiian monk seals in the MHI consumes around 1300 kg/day (2900 lbs/day, or about 15 lbs/day per seal), which is a maximum of 0.009% of the estimated available prey biomass.
- The biomass of apex predatory fish in the MHI near-shore marine ecosystem is estimated to be more than 80 times the biomass of the Hawaiian monk seal population, and apex predatory fish likely consume at least 50 times more biomass daily than the monk seal population.
- Recreational and commercial fisheries in the MHI (excluding pelagic species) together are estimated to land ~ 3 times more near-shore marine resources than are consumed by monk seals.
- An estimated 27% of commercial fishery landings and 39% of recreational fishery landings (by weight, excluding pelagic species) are from fish families found in the monk seal diet.

A full evaluation of the role of monk seals in the marine ecosystem would require a comprehensive model detailing the complex interactions between species, including human fishermen. Given data limitations, this study gives perspective and context to monk seal consumption, with reasonable estimates of ecosystem biomass and other species' consumption. On this broad level, inter-species interactions are complex and there is no evidence that Hawaiian monk seals have a significant effect on any one species that exceeds the effects of other apex predatory fish or human fisheries. We find no support for assertions that Hawaiian monk seals have an ecosystem-level negative impact on marine resources or fisheries in the main Hawaiian Islands. Our understanding of the ecological interactions between monk seals and fisheries would be improved by better reporting of fishery landings, especially from subsistence and recreational fisheries. Ongoing studies with direct observation of Hawaiian monk seal foraging behaviors will help illuminate potential localized effects. There are other areas where available data can be improved (e.g., assessment of coral reef biota in depths > 30 m), and this analysis will be revisited in the future as conditions and available information change.

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CONTENTS

1 INTRODUCTION

The Hawaiian monk seal (*Monachus schaunislandi*) is the most endangered marine mammal found entirely in U.S. jurisdiction, with only about 1100 individuals remaining. The overall population is in decline, but a small population of seals in the main Hawaiian Islands (MHI) has been increasing in recent years. While encouraging, the increasing MHI population has created a new and diverse set of management challenges, including an increased frequency of interactions with humans, and concerns about potential competition (direct and indirect) with fishermen – both for space (e.g., beach access) and for marine resources.

Members of the fishing community and others have raised questions about monk seal consumption of fish and other marine fauna, and the effects of monk seals on other components of the marine ecosystem around the MHI. While many of the questions focus on the amount that monk seals eat, an estimate of food consumption alone is not particularly informative without a broader ecological perspective, e.g., information about the amount of available prey, types of prey selected by monk seals, and consumption by other predators. In this report, we took this broader viewpoint by estimating monk seal biomass and their consumption relative to available food resources in the MHI nearshore marine ecosystem, biomass eaten by other apex predators, and the degree of overlap of monk seal diet with the catch of commercial and recreational fisheries.

Even with a broader view, this analysis does not take into account complex indirect interactions between species in the ecosystem. For example, some prey species that monk seals eat may be targeted by fisheries, but also may be species that are competitors or predators of targeted species. To take such interactions into account, we would need to develop a comprehensive model of the MHI near-shore ecosystem including monk seals, fishes, other forage species, and human fishermen. Because of severe data limitations, such a model is beyond our present capacity. So while this study is not meant to be a precise scientific characterization of monk seals and their role in the ecosystem, it serves to give perspective to current monk seal consumption with reasonable estimates of biomass and other species' consumption. It will be some time before suitable information exists to create a full ecosystem model. Nevertheless, the findings of our analysis will be valuable from a management perspective to better understand the role of Hawaiian monk seals in the marine ecosystem of the MHI and provide this information to address questions and concerns from fishing communities, ocean users, and the general public. The results will be used to inform education and outreach efforts of NOAA's National Marine Fisheries Service (NOAA Fisheries) and its partners. The results may be helpful in regulatory compliance documents, such as the Programmatic Environmental Impact Statement for Hawaiian Monk Seal Recovery Actions currently being prepared by NOAA Fisheries.

1.1 Questions Addressed in the Analysis

Overarching Questions: What is the role of monk seals in the MHI ecosystem and how do they affect or overlap with recreational, subsistence, and commercial fisheries in the MHI?

Specific Questions;

Part A: Biomass availability and relative prey consumption

- How does monk seal abundance or biomass compare to other apex predatory fish in the MHI?
- What biomass of food resources is available to marine apex predators in the MHI?
- How much do monk seals eat?
  … Relative to the estimated prey biomass available in the MHI?

  … Relative to the estimated amount eaten by apex predatory fish in the MHI?

  … Relative to estimated commercial and recreational fisheries landings from the MHI?

Part B: Prey overlap between fishery landings and Hawaiian monk seal diet

- To what extent does monk seal diet in the MHI overlap with the catch composition of commercial and recreational fisheries from the MHI?

2 ANALYSIS

Among the important considerations in conducting this analysis was our intention to avoid underestimating the possible effects of Hawaiian monk seals on the ecosystem or fisheries. In keeping with this objective, we exercised caution when stipulating the values for key variables that influenced the outcome of the analysis. We used the best available data to estimate a reasonable mean or range for parameters like biomass and consumption rates. In cases where there was considerable doubt or uncertainty, and hence a broad range of plausible values, we erred on the side of *over*estimating the potential monk seal impacts (e.g., population size or consumption rate), while *under*estimating the available resources and human impacts (e.g., available biomass or fishery landings). We took this approach to ensure that any conclusions we make tend to overestimate potential monk seal impacts, and similarly underestimate potential impacts of human extraction on monk seals.

2.1 Variables Used in the Analysis

In many cases, peer-reviewed or published values for key variables needed in the analysis were not available. In those cases, we derived values using the best available comparative data and specified the necessary assumptions (as below). Throughout, we rounded to the appropriate number of significant figures. The key variables used in the analysis are:

Part A: Biomass availability and relative prey consumption

Variables related to biomass

- Standing biomass (kg) – standing biomass is an estimate of the biomass at any given time. This variable was estimated from:
  - Monk seal foraging habitat area in MHI (for each island) (km^2)
  - Overall density of fish (kg fish/km^2 of monk seal foraging habitat)
    - For each island
    - For each trophic level (apex, secondary, herbivore, planktivore)
- Monk seal biomass in the MHI. This variable was estimated using the following:
  - Estimated number of seals in the MHI
  - Average body mass for each age or size class (kg)

Variables related to consumption

- Monk seal daily food consumption (kg/day). This variable was estimated from:
  - Estimated individual energy consumption (kcal/day)
  - Estimated caloric value of prey (kcal/g)
  - Predicted individual food consumption rate (kg/day or % of body mass/day)
  - Total MHI monk seal population daily consumption (kg/day)
- Apex predatory fish daily biomass consumption (kg/day). This variable was estimated from:
  - Apex predatory (reef) fish biomass (kg)
  - Predicted apex predatory fish consumption rate (% of body mass/day)
- Consumption by humans (fishery landings). This variable was estimated from:
  - Commercial fishery landings (kg/day)
  - Recreational fishery landings (kg/day)

Part B: Prey overlap between fishery landings and Hawaiian monk seal diet

Extent of prey overlap between fishery landings and Hawaiian monk seal diet.

- This variable was estimated from:
  - Relative prevalence of different fish families in monk seal diet and in fisheries landings

2.2 Part A: Available Biomass and Relative Biomass Consumption

2.2.1 Biomass

2.2.1.1 Standing Biomass

Estimates of marine biomass that might be available to monk seals in the MHI are not available. To derive a minimum estimate of standing biomass that might be available as food to monk seals in the MHI, we used published estimates of foraging habitat area and fish densities.

Foraging Habitat:

Hawaiian monk seals are known to forage in habitats ranging from coral reefs, sandy bottom, and rubble flats, down to the sub-photic slopes (Parrish et al. 2005, Stewart et al. 2006, Parrish and Littnan, 2008). In the MHI, analysis of 12 GPS cell-phone tagged seals shows that 97.7% of dives are 200 m or shallower (NOAA Fisheries Pacific Islands Fisheries Science Center (PIFSC) Hawaiian Monk Seal Research Program (HMSRP), unpublished data). The area within the 200 m isobath is thus the best estimate of the area over which Hawaiian monk seals may forage, given the information we have from studies in the NWHI and the ubiquity of Hawaiian monk seal movements across habitats in the MHI (PIFSC HMSRP, unpublished data). However, this may exaggerate actual monk seal foraging habitat and is delineated by depth, not by presence of different types of habitat within that area. While seal movements have been tracked with GPS tags in both the NWHI and MHI, camera work to detail specifically how monk seals use different habitats and in what types of habitat they forage has only been completed in the NWHI (Parrish et al., 2005, Parrish and Littnan, 2008). A 3-year camera research study in the MHI started in 2012 and will inform future analyses.

To calculate standing biomass available for monk seal consumption in the MHI, it is necessary to have estimates of both monk seal foraging habitat area and prey density in those habitats. The only standardized estimates of prey density are fish density surveys conducted in the MHI in relatively shallow (< 30 m) coral reef habitat. We chose to use coral reef area estimates as representing monk seal foraging habitat for this analysis because they could be paired with the available fish density estimates.

There are several sources of coral reef area assessments in the MHI. Research groups at NOAA Fisheries PIFSC have mapped benthic habitat around the main Hawaiian Islands using several methods including IKONOS satellite and aerial photos (ground validated), and ship-based mapping techniques such as acoustic single- and multi-beam sonar, as well as optical video and still-camera observations. These data are combined by the PIFSC Coral Reef Ecosystem Division (CRED) to create integrated map products of the benthic habitat around Hawaii and the Pacific Islands (Battista et al. 2007, Williams 2010, PIFSC CRED unpublished data[1]). Another source is the coral reef estimate by Hunter (1995), which calculated coral reef area by multiplying estimates of mean reef width by the percent of shoreline that is predominantly reef habitat for each island. Hunter's estimate is more than twice the total coral reef area calculation

[1] These data were directly obtained from CRED's database in April 2013 and represent the most up-to-date benthic habitat maps available from NOAA Fisheries.

from Battista et al. (2007). However, because of how it was calculated, Hunter's calculation of reef area is hard to validate or assess.

Table 1.--Estimates of foraging area around the main Hawaiian Islands.

	Potential Foraging Area (km^2)	
	Total Area Within 200-m Isobath PIRO ArcGIS	**Coral Reef and Hardbottom < 30 m PIFSC CRED unpub. data**
Ni`ihau, Lehua & Ka`ula	423.43	92.66
Kaua`i	648.74	181.27
O`ahu	1,085.23	251.19
Maui	4,283.61	111.22
Moloka`i	(Maui Nui includes Moloka`i, Kaho`olawe, and Lānā`i)	127.30
Lānā`i		30.04
Kaho`olawe		unknown
Hawai`i	1,181.39	168.40
Total	7,622.40	962.08

The CRED survey data of coral reef and hard bottom are likely the most accurate representations of the nearshore marine environment around the MHI given their rigorous direct and integrative methodology. Additionally, this area estimate was one of the smallest and most conservative, and had paired fish density data available from the same CRED database. As a result, we used this data set for our estimate of standing biomass. CRED has habitat estimates for deeper areas (30–100 m), but does not yet have comprehensive fish density surveys for these depths given that it is out of safe reach of human divers with conventional methods. So the reef-area calculation we used does not include any area deeper than 30 m, and additionally does not include several bottom types, such as sand and mud, that monk seals use for foraging (Parrish et al., 2005), but for which fish density estimates are not available.

While it is difficult to estimate the specific proportion of monk seal foraging that occurs in the < 30-m shallow coral reef habitat, we note that that the CRED habitat area estimate is only 12.6% of the total area inside the 200-m isobath. So by limiting our calculation of standing biomass to this smaller area, we are excluding most of the area over which monk seals forage. Thus, any estimates in this analysis of Hawaiian monk seal and other marine predator consumption impact on the ecosystem as a percentage of standing biomass are likely greatly overestimated.

Reef Fish Density:

There are several studies that measure reef fin fish density in the MHI but none that include invertebrates. Two older studies (Friedlander and DeMartini, 2002; Rodgers, 2005) looked only at total reef fish biomass density and reported average densities between 40,000 and 100,000 kg/km^2. More recent studies have assessed densities of fish based on trophic levels (Friedlander et al., 2008; Friedlander et al., 2010; Williams, 2010; PIFSC CRED, unpublished data). The Friedlander et al. (2008 and 2010) and Williams (2010) studies used similar "open count" survey techniques where divers swim transects counting all fishes within and moving across the survey transect ahead of the diver during the entire period of the transect (10-15 minutes). They reported average reef fish densities in the main Hawaiian Islands between 24,000 and 126,000 kg/km^2 depending on the island. Survey techniques more recently used by CRED are more conservative in that they are a "closed count" survey involving repeatedly counting groups of fishes in rapid sweeps of the sample area. Additionally, the more recent CRED work surveyed more area but included more poor quality habitats, rather than focusing on smaller, better quality habitats to survey, which further lowers the density estimates. For this analysis, we used these recent and more conservative CRED reef fish density data (Table 2).[2]

Table 2.--Estimates of reef fish density around the main Hawaiian Islands.

	Reef Fish Density (kg/km^2)		
	Apex Predatory Fish	**Herbivores, Secondary Consumers, and Planktivores**	**Total**
	PIFSC CRED unpub. data		
Ni`ihau, Lehua, & Ka`ula	9,770	28,678	38,448
Kaua`i	2,320	14,119	16,439
O`ahu	397	6,967	7,364
Maui	1,332	17,345	18,677
Moloka`i	1,619	17,582	19,201
Lānaʻi	2,579	17,579	20,157
Kaho`olawe	—	—	—
Hawai`i	1,894	16,484	18,379
Mean	2,845	16,965	19,809

Standing Biomass Calculation:

$$\text{Fish biomass (kg)} = \text{reef area (km}^2\text{)} * \text{fish density (kg/km}^2\text{)}$$

In our calculation of nearshore standing biomass around the MHI (Table 3), we used reef area and fish density estimates from the PIFSC CRED database (unpublished data).

[2] Note that this data source does not include density estimates for Kaho`olawe. In other surveys, Kaho`olawe had the highest density of fish in the MHI.

Table 3.--Estimated biomass of apex predatory fish and herbivores, secondary consumers, and planktivorous reef fish in the main Hawaiian Islands.*

	Biomass (kg)		
	Apex Predatory Fish Biomass	**Herbivores, Secondary Consumers, and Planktivore Biomass**	**Total Biomass**
Ni`ihau, Lehua, & Ka`ula	905,315	2,657,311	3,562,626
Kaua`i	420,548	2,559,336	2,979,883
O`ahu	99,828	1,749,962	1,849,790
Maui	148,127	1,929,122	2,077,248
Moloka`i	206,121	2,238,204	2,444,325
Lāna`i	77,461	528,068	605,529
Kaho`olawe	—	—	—
Hawai`i	318,999	2,775,947	3,094,946
Total	2,176,399	14,437,949	16,614,348

* Source: PIFSC CRED unpublished data.

This calculation should be considered a minimum estimate of biomass available for Hawaiian monk seals and other apex predatory fish given the following assumptions and constraints.

Assumptions and Constraints:

- Assumes that reef fish density is constant across all depths < 30 m and coral reef sub-types around each island.
- Does not include biomass for Kaho`olawe, potentially the island with the highest fish density in the MHI (though a relatively small area).
- This is a minimum estimate of total MHI marine biomass given that it only includes hardbottom coral reef area out to 30-m depth; it excludes sandy and mud bottom habitats and all habitat in deeper depths in which monk seals are known to forage.
- Given the shallow < 30-m depth constraint, this biomass estimate does not include biomass for several other areas, in particular, Penguin Banks, a submerged former shield volcano off the west end of Moloka`i (depth generally ranging from 40 to 100 m) that is frequently used by monk seals for foraging.
- Monk seals are known to forage in depths beyond 30 m. Our analysis considered only hard bottom coral reef out to 30-m depth, representing just 12.6% of the area over which monk seals may forage. So our estimate of biomass greatly underestimates ecosystem biomass around the MHI.
- The estimates of biomass density only measured fin fish density, although we know monk seals and other apex predators also consume a large number of invertebrates.

Our calculation of minimum total reef fish biomass in the MHI is approximately 16,600,000 kg (36,600,000 lbs); herbivores, secondary consumers, and planktivores comprise at least 14, 400,000 kg (31,800,000 lbs), and apex predatory fish comprise approximately 2,200,000 kg (4,800,000 lbs) (Table 3).

Other estimates of standing biomass using alternate data sources discussed above can be found in Table 4. Even moderate changes in the data set used (particularly area estimates that incorporate deeper depths) can result in significant increases in calculations of standing biomass.

Table 4.--Estimates of near-shore standing biomass using alternate data sources.

Source		**Biomass (kg)**		
Reef Fish Density	**Area**	**Apex Predatory Fish Biomass**	**Herbivores, Secondary Consumers, and Planktivore Biomass**	**Total Biomass**
PIFSC CRED[1]	< 30 m *(PIFSC CRED)*	2,176,399	14,437,949	16,614,348
PIFSC CRED	< 200 m *(Arc GIS)*[2]	4,070,939	25,737,083	29,808,022
Williams, 2010	< 30 m *(Williams, 2010)*	722,361	43,000,893	43,723,254
Friedlander et al., 2008 & Friedlander et al., 2010	< 30 m *(PIFSC CRED)*	3,570,860	59,680,170	63,251,030
Friedlander et al., 2008 & Friedlander et al., 2011	< 100 m *(Hunter 1995)*	16,041,000	160,490,000	176,531,000

[1]PIFSC CRED unpublished data obtained in April 2013. The biomass estimates derived from this data set are used the analyses presented in this paper.

[2]There have been no comprehensive surveys of fish density in waters deeper than 30 m around the main Hawaiian Islands. To take into account the likely lower density of fish in deeper waters, this calculation used PIFSC CRED fish densities for 0–30 m and applied 10% of the 0–30 m fish densities to the area 30–200 m.

2.2.1.2 Total Monk Seal Biomass in the MHI

In 2011, there were 146 different seals identified in the MHI, distributed across four different age classes: adult, subadult, juvenile, and pups (Table 5; NMFS, 2011). There are some seals in the MHI that are not uniquely identified (particularly those that primarily use Ni`ihau, Lehua, or Kaho`olawe and may not be observed elsewhere). Therefore, the true number of seals in the MHI is unknown, but is some number larger than 146. In our analysis, we assumed a population of 200 seals in the MHI, which we believe is currently the likely high end of the range of possible population sizes bracketing the true value, given the likely density of seals on Ni`ihau, Lehua, or Kaho`olawe, or not observed elsewhere. Although the MHI monk seal population appears to be increasing, the rate of increase is such that the MHI population is unlikely to exceed 200 seals for the next 2–3 years.

For the average body mass of an individual Hawaiian monk seal of each age class, we used masses from the French Frigate Shoals Ecopath model in Parrish et al. (2011). The Ecopath model body mass data are from monk seals in the Northwestern Hawaiian Islands (NWHI). Because young animals in the MHI are observed to be larger than those in the NWHI, we estimated average body masses of subadult and juvenile sizes classes in the MHI by adding 10% to the equivalent NWHI values (Table 5, column 3). The total estimated biomass of the individually identified seals in the MHI is 18,900 kg (41,667 lbs).

Table 5.--Population size and biomass of individual monk seals identified in the MHI during 2011.

	Number	**Percent of Population (%)**	**Average Body Mass (kg/seal)**	**Total Monk Seal Biomass (kg)**
Adult (5+ yrs)	71	49	170.0	12,000
Subadult (3–5 yrs)	27	18	140.0	3,700
Juvenile (weaning to 3 yrs)	48	33	66.0	3,200
Total	146	100	—	18,900

To calculate the biomass of the assumed 200 monk seals in the MHI (Table 6, column 3), we assumed that the 200 seals were distributed across age classes with the same proportions as observed in the 146 individually identified MHI seals (49% adults, 18% subadults, 33% juveniles; Table 6, column 1).

For an assumed MHI population of 200 seals, the total biomass is estimated to be 26,100 kg (57,540 lbs; Table 6, column 3).

Table 6.--Estimates of population, population biomass, and daily consumption for three age classes of Hawaiian monk seals. Footnotes detail the calculations used where applicable.

	1	2	3	4	5	6	7	8
	Population		**Population Biomass**	**Individual Consumption**				**Population Consumption**
Age Class	**Assumed number of monk seals**	**Average body mass (kg/seal)**	**Total monk seal biomass (kg)[1]**	**Estimated individual energy consumption (kcal/day/seal)[2]**	**Biomass consumption (kg/day/seal)[3]**	**Biomass consumption rate (% body mass/day)[4]**	**Adjusted biomass consumption rate used for analysis (%)**	**Total Biomass Consumption (kg/day)[5]**
Adult (5+ yrs)	97	170	16,500	7009	5.89	3.5	4	660
Subadult (3–5 yrs)	37	140	5200	9154	7.61	5.5	6	312
Juvenile (weaning to 3 yrs)	66	66	4400	5963	5.01	7.6	8	352
Total	200	—	**26,100**	—	—	—	—	**1324**

[1] (1) number of seals * (2) average body mass (kg/seal)

[2] (*a**(body mass)^*b**(1.10)); values for *a* and *b* found in Appendix A

[3] (4) daily energy consumption / 1.19 kcal/g / 1000 (average caloric content of common prey items; see Table 7)

[4] (5) daily biomass consumption / (2) average body mass

[5] (7) biomass consumption rate * (3) total monk seal biomass

2.2.1.3 Comparison of Hawaiian Monk Seal and Apex Predatory Fish Biomass

The total biomass of herbivores, secondary consumers, and planktivores (16,600,000 kg) is estimated to be more than 600 times the assumed total biomass of Hawaiian monk seals (26,100 kg) in the MHI. Apex predator biomass (2,200,000 kg) is estimated to be more than 80 times the biomass of monk seals in the MHI (Fig. 1, Table 10).

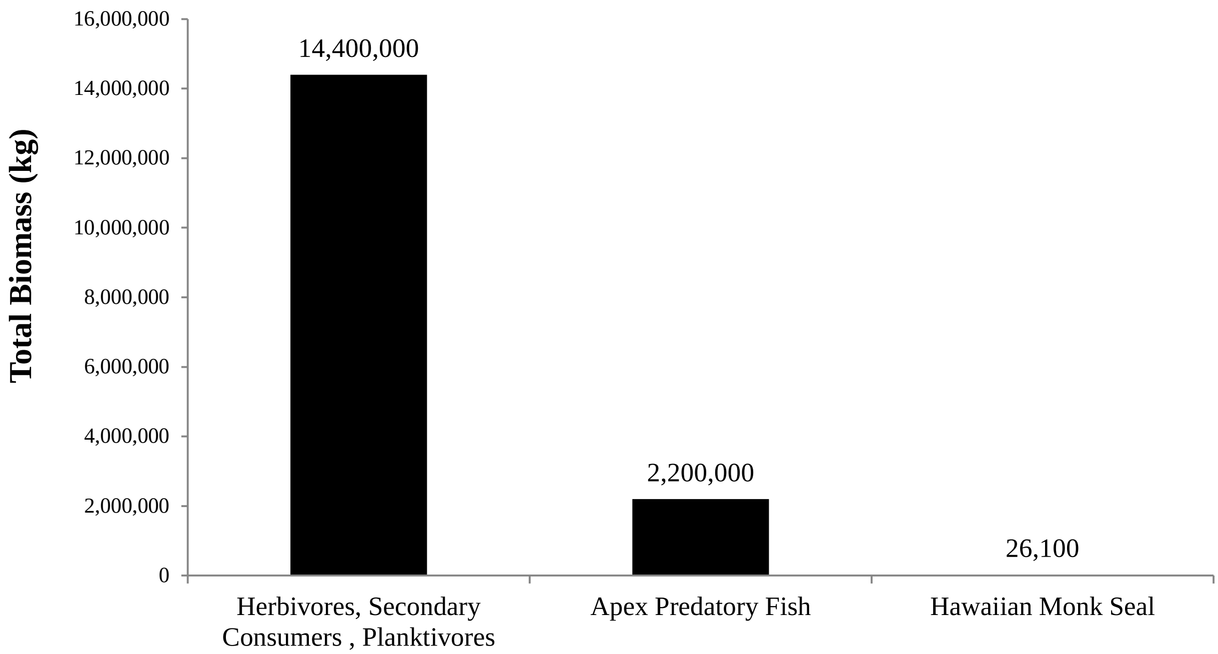

Figure 1.--Total estimated biomass of herbivores, secondary consumers, and planktivores, apex predatory fish, and Hawaiian monk seals.

2.2.2 Prey Consumption

2.2.2.1 Daily Consumption of Prey Biomass by MHI Monk Seals

Estimates of the daily consumption of wild monk seals as a percentage of their body weight are not available, but estimates for many other large marine and terrestrial wild carnivores range from 4% to 10% of their biomass. The only records of Hawaiian monk seal energy or biomass consumption are obtained from captive seals and are still very limited in their applicability to the entire population for this analysis: we could not create a model to predict consumption by different age classes from just 3 captive individuals. To address this issue, we used a published model of consumption to project potential monk seal daily consumption rates for different age classes, and compared those predicted values with the few observed consumption rates of individual Hawaiian monk seals in captivity to confirm that the predicted values were in a realistic range.

There are several methods of estimating consumption, including equations relating energy or biomass ingestion to individual weight (Innes et al., 1987; Powers and Backus, 1987; Read and Brownstein, 2003), estimates of basal metabolic rate (Hammill and Stenson, 2000; Stevick et al., 2008; Iverson et al., 2010), and models including interactions between consumption and prey resource density (Yodzis and Innes, 1992; Yodzis, 1994). Based on the information available for estimating marine mammal consumption, we used the standard allometric equation for the relationship between energy or biomass consumption and individual body mass:

$$C = aM^b$$

where *C* is consumption (in kg/day or kcal/day) and *M* is body mass (in kg). In this equation, "*a*" and "*b*" are parameters that vary by taxonomic group, age class (e.g., juvenile or adult), and energetic state (e.g., growing or maintenance). The values we used for "*a*" and "*b*" in predicting biomass ingestion and energy ingestion (Appendix A) are based on an analysis of empirical food consumption measurements from 205 species of seals and whales and 148 terrestrial carnivores of known body mass (Innes et al., 1987). In developing their relationship parameters, Innes et al. primarily relied on data for temperate and arctic species of seals (Hawaiian monk seals are the only tropical true seal in the world). However, the energy content of prey eaten by different seal species can vary considerably, and a simple prediction of the rate of biomass consumption may fail to take into account differences in prey quality. To address this concern, we began with a comparison of predicted versus observed consumption based on energy intake instead of mass intake.

Predicted Individual Energy Consumption:

Williams et al. (2011) directly measured resting metabolic rate of a single juvenile male Hawaiian monk seal in captivity (resting metabolic rate of the seal resting in water was 2802 kcal/day). In other marine mammals, field metabolic rates are about three times resting rate (Costa and Williams, 1999; Williams et al., 2004). If this relationship also holds true in monk seals, Williams et al. predicted that field metabolic rate for a free-ranging juvenile monk seal (~ 80kg) would be 8406 kcal/day. This is ~ 30% greater than predicted for an 80 kg juvenile phocid by the Innes et al. model.

We next compared the observed energy consumption of 3 captive monk seals to the energy consumption predicted for these seals using the allometric equation above. As shown in Table 7, these captive monk seals consumed 6–10% fewer calories per day than were predicted by the consumption equation. We added an additional 10% to the predicted values for energy consumption to further overestimate this parameter and take into account the increased activity budget of free-ranging seals. As a result, consumption values used for this analysis were ~ 20% more than the observed consumption rates for captive monk seals. Table 6 shows the estimated body mass (column 2) and predicted energy consumption (column 4) for wild adults, subadults, and juveniles (assuming that adults are maintaining mass, while subadults and juveniles are growing).

Table 7.--Predicted vs. observed consumption of Hawaiian monk seals in captivity.

ID	Maturity	Energetic State	Mass (kg)	Energy Ingestion (kcal/day) Predicted	Observed	% Difference
Nuka	adult	maintenance	186	6847.5	6437	– 5.99
Maka	adult	maintenance	170	6372.0	5719	– 10.25
KP2	adult	growing	95	6671.6	6200	– 7.07

*Mass and observed energy ingestion for Nuka and Maka were averaged from 2001 to 2007.

Caloric Value of Common Prey:

To convert the estimates of energy intake discussed above into estimated biomass consumed by monk seals, we examined the energy content of common monk seal prey items. Given the monk seals' broad diet, we used the average caloric value of common monk seal prey species, which is 1.19 kcal/g (Table 8; range = 0.67–1.7 kcal/g).

Table 8.--Nutrient content (based on wet weight) of common prey items of Hawaiian monk seals (from Goodman-Lowe et al., 1999), assuming the widely accepted energetic content of 4 kcal/g of protein, 9 kcal/g of fat, and 4 kcal/g of carbohydrates.

Prey Species	Common Name	Crude Protein (%)	Crude Fat (%)	Carbohydrate (%)	Gross Energy (kcal/g)
TELEOSTS					
<u>Labridae</u>					
Anampses cuvier	Pearl wrasse	20.2	2.2	8.6	1.35
Bodianus bilunulaus	Tarry hogfish	19.0	0.1	7.2	1.06
Gomphosus vairus	Birdnose wrasse	20.6	1.1	9.2	1.29
Oxycheilinus unifasciatus	Ringtail maori wrasse	21.5	0.4	8.0	1.22
Thalassoma ballieui	Blacktail wrasse	22.0	1.6	11.1	1.47
<u>Scaridae</u>					
Chlorurus perspicillatus	Spectacled parrotfish	14.6	0.1	8.1	0.92
<u>Holocentridae</u>					
Myripristis amaena	Brick soldierfish	20.3	1.8	10.1	1.38
Neoniphon sammara	Sammara squirrelfish	20.8	3.5	13.7	1.70

Table 8 *continued*.

Prey Species	**Common Name**	**Crude Protein (%)**	**Crude Fat (%)**	**Carbohydrate (%)**	**Gross Energy (kcal/g)**
Balistidae					
Melichthys vidua	Pinktail triggerfish	16.7	2.6	6.5	1.16
Sufflamen fraenatus	Masked triggerfish	15.9	0.9	10.7	1.15
Muraenidae					
Gymnothorax eurostus	Abbott's moray eel	20.0	4.9	8.7	1.59
G. ruppelliae	Banded moray eel	21.6	0.3	5.2	1.10
G. undulatus	Undulated moray eel	19.8	3.5	7.8	1.42
Congridae					
Conger cinereus	Longfin African conger	20.1	0.5	4.1	1.01
Kuhliidae					
Kuhlia sandvicensis	Hawaiian flagtail	20.9	2.1	4.6	1.20
CEPHALOPODS					
Octopoda					
Octopus cyanea	Day octopus	13.5	0.1	3.1	0.67
Teuthodea					
Loligo sp.	Common squid	12.8	0.2	3.9	0.69
CRUSTACEANS					
Decapoda					
Panulirus marginatus	Spiny lobster	13.7	0.2	12.2	1.06
MEAN		18.6	1.4	7.9	**1.19**

Predicted Daily Individual Monk Seal Biomass Consumption Rate:

Based on an average of 1.19 kcal/g in the common prey items of Hawaiian monk seals, Table 6 (columns 5 and 6) shows calculations of the biomass of prey and the percent body mass that monk seals would have to eat to meet the projected caloric demand (column 4). We rounded our results up to the nearest whole percentages of 4% (adults), 6% (subadults), and 8% (juveniles) for use in the remaining analyses (Table 6, column 7). Higher relative consumption rates for younger animals reflect higher metabolism as a result of greater levels of growth and development.

We have chosen these values to err on the side of overestimating monk seal impacts as explained in the introductory paragraph of the Analysis (Section 2.0).

Summary of Total Daily Monk Seal Prey Biomass Consumption:

The MHI Hawaiian monk seal assumed population is estimated to eat approximately 1300 kg/day (2900 lbs/day) of biomass (Table 6, column 8). This is an average of ~ 15 lbs/day per seal (with 200 seals in the MHI).

This calculation is based on:

- Assumed population size of 200 seals in the MHI (97 adults, 37 subadults, and 66 juveniles/pups)
- Estimated consumption rate of 4% of body mass for adults, 6% for subadults, and 8% for juveniles

This likely exceeds the actual prey biomass consumption by monk seals given that we inflated the following:

- Number of seals in the MHI (~ 37% more than observed)
- Average mass of juvenile and subadult age classes (10% more than observed in the NWHI)
- Predicted daily energetic consumption of wild seals (15–20% more than observed in captive seals, taking into account the difference between energy consumption by wild seals vs. captive seals)
- Predicted daily biomass consumption rate (5–15% more than calculated)

2.2.2.2 Daily Consumption of Prey Biomass by Apex Predatory Fish

Apex Predatory Fish Daily Consumption Rate:

The nearshore apex predatory fish community composition in Hawai`i is dominated by giant trevally (*Caranx ignobilis*), blue trevally (*Caranx melampygus*), Galapagos shark (*Carcharhinus galapagensis*), whitetip reef shark (*Triaenodon obesus*), gray reef shark (*Carcharhinus amblyrhynchos*), and gray snapper (*Aprion virescens*) (Friedlander and DeMartini, 2002). The daily consumption rate for the Hawai`i apex predatory fish community was estimated from empirical studies of similar species (Table 9).

On average, carangids have a higher consumption rate than sharks. Our estimate of apex predatory fish consumption rate, based on mean observed consumption rate, was 3.00% (Table 9), weighting carangids and elasmobranches equally. However, carangids may make up more than 50% of the MHI apex predator community, so our consumption estimate would be skewed low by the overrepresentation of sharks (PIFSC CRED, pers. comm.).

Table 9.--Daily consumption rate by different species of apex predatory fish.

Species	Common Name	Daily Consumption (% Body Mass/Day)	Range (%)	Reference	Primary Habitat
Caranx melampygus	Bluefin trevally or blue ulua	5.12	3.85–9.04	Sudekum et al. 1991	tropical, subtropical
Caranx ignobilis	Giant trevally or ulua	4.17	2.94–6.44	Sudekum et al. 1991	tropical, subtropical
Carangid Mean		**4.65**			
Negaprion brevirostris	Lemon shark	1.80	1.5–2.1	Cortes 1987	tropical, subtropical
N. brevirostris		1.20	0.4–2.0	Clark 1963	
Carcharhinus plumbeus	Sandbar shark	1.10		Medved et al. 1988	tropical, temperate
Squalus acanthias	Spiny dogfish	1.30		Jones and Geen 1977	temperate
Elasmobranch Mean		**1.35**			
Overall Mean		**3.00%**			

Assumptions and Constraints:

- Assumes the consumption rates of the Hawaiian apex predatory fish community are reflected in the composition of species used to determine the mean
- Assumes that carangids and elasmobranches each comprise half of the apex predatory fish community biomass
- Assumes consumption of other species of apex predators is comparable to the consumption by 2 species of carangid and 3 species of elasmobranch

Total Apex Reef Fish Prey Consumption Calculation:

Total apex predatory (reef) fish consumption (kg/day) =

Apex predatory fish biomass (kg) * consumption rate (% mass/day)

Based on an estimated standing stock of 2,200,000 kg of apex predatory fish, and a consumption rate of 3% body mass/day, apex predatory fish around the MHI are estimated to eat a minimum of 66,000 kg/day (146,000 lbs/day).

2.2.2.3 Commercial and Recreational Fishery Landings

Here, we examine the amount of marine biomass removed from the ecosystem by humans in the form of commercial and recreational fish catch in relation to monk seal consumption. For all consumption calculations, we used estimates of daily fishery landings and daily monk seal consumption compared to standing biomass. Daily rates were used because standing biomass estimates are actually "instantaneous" estimates, so using a landing rate or consumption rate measured in units per day is more comparable to an instantaneous value than measurements in units per year.

The data from fishery landings are made up of broad categories (not species) and include several groups of fish that are not eaten by Hawaiian monk seals (e.g., barracudas, jacks). However, we used these data to compare the magnitude of the overall biomass removed by the fishery, vs. that consumed by monk seals and apex predatory fish.

Fishery Landings Data Sources

Commercial Fishery Landings:

For commercial fishery landings, we used data published by the State of Hawai`i Department of Land and Natural Resources (DLNR) (DLNR, 2003, 2004, 2005, 2006, 2007, 2008, 2009). DLNR reports sea landings of species in pounds (lbs) and separates them into about 170 groups, mostly according to family (Appendix B). We averaged data for each family from 2003 to 2009 and calculated a daily average by taking the overall yearly average and dividing by 365.

For this biomass consumption comparison, we included landings of reef fish families, but excluded landings of pelagic species (e.g., billfishes, tunas, mahimahi) and deep bottomfishes because they likely do not overlap spatially with the area over which we calculated biomass (Section 2.2.1). We also did not include harvest of groups like corals and seaweeds that are not considered in our calculations of ecosystem biomass. By excluding the pelagics and deep bottomfishes, we excluded 95% of the total landings reported by commercial fisheries.

Recreational Fishery Landings:

In Hawai`i, the line between recreational and subsistence fishing is blurred, and there is little collection of data to differentiate between the two. There is no saltwater fishing license for recreational or subsistence fishing, and no requirement to report recreational catch in the State of Hawai`i. As a result, the data on recreational fishery landings are very limited and are considered by some to be biased or incomplete and represent a minimum estimate of extraction. In 2001, NOAA Fisheries and the Hawai`i Department of Land and Natural Resources, Division of Aquatic Resources (DAR) began collecting marine recreational fishery data in Hawai`i, administered through the Hawai`i Marine Recreational Fishing Survey (HMRFS).[3] Query parameters and outputs are shown in Appendix C. For each fish family, we averaged annual landings data from years 2003-2011 and divided the result by 365 to estimate average daily landings. In computing the total landings and landings per day, we excluded fish caught > 3 miles from shore and further excluded pelagic species (e.g., dolphin fish (mahi-mahi), tunas, and mackerels), sharks, and unknown species from the analysis, even if caught within 3 miles. By excluding these groups, we excluded 90% of the total catch reported by recreational fisheries.

2.2.2.4 Comparison of Estimated Fisheries Landings and Prey Consumption by Hawaiian Monk Seals and Other Apex Predators

We estimate that apex predatory fish consume at least 50 times as much biomass daily as Hawaiian monk seals in the MHI (Table 10). Overall, the biomass taken by monk seals on a daily basis is less than the nearshore catch by commercial and recreational fisheries individually. Fisheries combined (excluding pelagic species and recreational catch from outside of 3 miles) take about 3 times more biomass daily than monk seals consume (Fig. 2, Table 10).

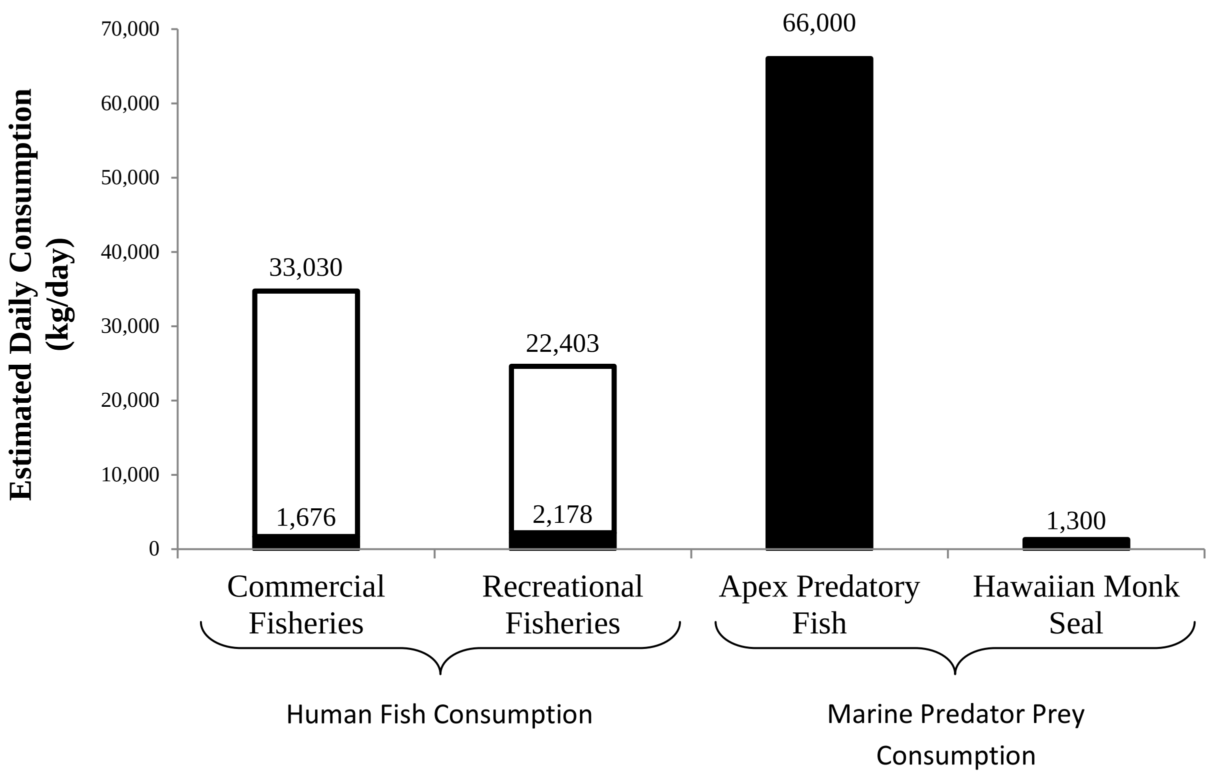

Figure 2.--Estimated daily consumption (kg/day) by commercial fisheries (clear outline indicates total reported catch, shaded area excludes pelagic species), recreational fisheries (clear outline indicates total reported catch, shaded area excludes pelagic species and catch from > 3 miles from shore), apex predatory fish, and Hawaiian monk seals.

[3] We acquired data by querying the NOAA Marine Recreational Fishing Survey Statistics (MRFSS) website (http://www.st.nmfs.noaa.gov/recreational-fisheries/access-data/run-a-data-query/queries/index) that provides access to summarized recreational fishery catch from 2003 to 2011.

Table 10.--Comparison of biomass, estimated daily consumption, and % daily consumption of total biomass for apex predatory fish, fisheries, and Hawaiian monk seals.

Group	**Biomass (kg)**	**Estimated Daily Consumption (kg/day)**	**% Daily Consumption of Total Biomass**
Herbivores, secondary consumers, planktivorous fishes	14,400,000	—	—
Apex predatory fish	2,200,000	66,000	0.458
Commercial fishery (average daily landings 2003-2009)[1]	—	—	—
Total		33,030	0.2294
Excluding pelagic species		1,676	0.0116
Recreational fishery (average daily landings 2003-2011)[2]	—	—	—
Total		22,403	0.1556
Excluding pelagic species *and* > 3 mi		2,178	0.0151
Hawaiian monk seals	26,100	1,300	0.0090

[1]Data Source: DLNR Commercial Catch Reports (DLNR, 2003, 2004, 2005, 2006, 2007, 2008, 2009)
[2]Data Source: NOAA Marine Recreational Fishing Survey Statistics (MRFSS) website, (http://www.st.nmfs.noaa.gov/ recreational-fisheries/access-data/run-a-data-query/queries/index, data extracted November 13, 2012)

Assumptions and Constraints:

As described above, commercial fishery landings data were obtained from mandatory fisher reports of daily fishing activity, while recreational fishery landings data were obtained from voluntary surveys. Both may underreport the actual catch, but there is likely greater accuracy in the commercial data. In the recreational fishery in particular, reported nearshore recreational landings from spearfishing and shoreline fishing may not be as well represented as boat-based landings (T. Ogawa, pers. comm., DLNR DAR).

- Comparing monk seal consumption with fishery landings also assumes that the comparison is meaningful and that seals and fishing gear are in direct competition for the same individual fish. That is, we assume there is continual spatial and temporal co-occurrence of foraging monk seals and fisheries at fine scales; however, we know that this is not always the case.
- This comparison assumes that monk seals, apex predators, and fisheries each consume the same proportion of various prey types (i.e., same selectivity), even though we know from studies of these animals' diets and foraging habits that this is incorrect. The next section addresses this inconsistency by assessing the overlap between fisheries and Hawaiian monk seal diet.

2.3 Part B: Prey Overlap Between Fishery Landings and Hawaiian Monk Seal Diet

Much of the interest in Hawaiian monk seal consumption stems from a desire to understand what and how much Hawaiian monk seals consume relative to human consumption. In Part A of this analysis, we compared total biomass consumed by monk seals with amounts of biomass harvested by commercial and recreational fisheries. However, we must acknowledge that monk seals and fisheries may target different types of fish, or different sizes of the same species, and they may hunt those fish at different times over different areas. Additionally, even within the overlapping groups of fish targeted by both monk seals and fisheries, those groups do not necessarily comprise the same relative proportion of diet for monk seals as they do for fisheries. In this section, we do not directly compare biomass consumed, but instead examine the relative prevalence, or proportion, of different fish families in monk seal diet and in fishery landings.

2.3.1 Composition of Fishery Landings

The taxonomic composition of commercial fishery landings (Appendix B) and recreational landings (Appendix C) was compiled by fish family. We expressed the relative prevalence of different fish groups landed by fisheries as the percent weight of reported or estimated fishery landings (see data sources above, Section 2.3.3).[4] As above, we excluded pelagic species and recreational catch from > 3 miles from shore. Because the comparison of diet requires known catch or consumption from specific families of fishes, we also excluded "miscellaneous inshore fishes" and "other fishes" from the commercial and recreational fishery calculations, respectively.[5] The objective in this section is to compare the most prevalent fish families found in Hawaiian monk seal diet with fish families most prevalent in nearshore human fishery landings. As a result, some fish families are included that Hawaiian monk seals do not eat (e.g., ulua and akule/opelu) and in the same way, fish and invertebrates that Hawaiian monk seals eat are included when they may not necessarily be targeted by fisheries. All of these fish families are found in the nearshore areas (i.e., within 3 miles from shore) over which we calculated biomass, so we feel this is the most accurate way to compare the relative fish consumption by monk seals and by fisheries.

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[4] During the final review of this analysis, we became aware of a new study of recreational fishery landings by Williams and Ma (PIFSC, unpublished data). Their manuscript is currently undergoing review as a PIFSC Administrative Report and thus, we were not able to include their data in this analysis. We re-ran the diet overlap analyses in Section 2.3 using the Williams and Ma data. While the Williams and Ma calculations do change the recreational fishery landings in several groups of near-shore reef fish, the percentage of overlap with Hawaiian monk seal diet and overall conclusions of this analysis are not significantly changed.

[5] By "excluding" most of the commercially important fish like tunas, mahimahi, deep bottomfish, etc. (~ 95% of the landed weight in commercial and recreational fisheries), we increased the relative importance of remaining families caught by fisheries relative to families of fishes prevalent in monk seal diet. If we included deep bottomfish, tunas or any other fishes not found in monk seal diet in the total weight used to calculate "% landed weight," we would decrease the percent weight landed in other families currently included, such as surgeonfishes, making that family appear less "important" to, or less prevalent in human fisheries.

2.3.2 Hawaiian Monk Seal Diet Data Sources

Determination of diet for free-living wild mammals can be done in several different ways, each with different limitations and biases. First, some prey species identification may be made from direct observation (e.g., National Geographic Crittercam), though these opportunities tend to be rare and only capture a limited number of predation events. This lack of direct observation has led to the development of a number of other techniques to assess marine mammal foraging.

Information on the diet composition of marine mammals has mostly been obtained from recovery of hard parts of prey from feces and stomach contents. This is a broadly used and accepted method of diet analysis, but it is known to have potential biases, owing to differential rates of digestion and passage of various structures of different fishes and invertebrates, and diet estimates derived from this method represent species that were consumed relatively recently.

A number of other techniques have been developed to analyze diet including stable isotope analysis, fecal DNA, and fatty acid analysis. Of these, the only technique that has been applied to monk seal ecology in any significant way is fatty acid analysis. Analyses of dietary fatty acids (FAs) have helped resolve some of the biases discussed above for several marine mammals and seabird species. An effort was begun in 1998 to determine whether quantitative FA signature analysis (QFASA) could be used to better characterize the diet of monk seals, and perhaps resolve the biases with use of hard parts of prey in fecal analysis (Iverson et al., 2011). The QFASA analyses focused primarily on seals in the NWHI, and only 15 seals from the MHI were sampled. Results from the MHI QFASA analysis indicated that the average seal diet was composed primarily of deeper dwelling species. However, this is in contrast to diving data collected from more than 60 MHI monk seals, which indicates almost all monk seal dives are shallower than 200 m and many seals stayed shallower than 100 m (PIFSC HMSRP, unpublished data). The proportion of deeper diving/feeding seals in the QFASA study may not be representative of the larger MHI population, so the results may be biased. Until samples from more seals can be analyzed, this data set should not be used to assess monk seal diet in the MHI.

For this analysis, Hawaiian monk seal diet composition was determined from hard parts (e.g., bones, scales) in 120 fecal and regurgitate samples collected from monk seals in the MHI between 2000 and 2009 (see detailed methods in Cahoon 2013). We calculated several indices to convey the relative importance of different families in monk seal diet:

Frequency of Occurrence (FO): FO represents the number of samples in which a prey type was found. The percent frequency of occurrence (% FO) is FO, divided by the total number of samples analyzed (multiplied by 100). This calculation can overstate the importance of prey species that occur in many different samples, but in very small numbers or volume.

Numerical Abundance (NA): NA is the total number of individuals of a prey type across all samples. The percent numerical abundance (% NA) of a certain prey type is the NA of that prey, divided by the total number of individual prey identified in all samples (multiplied by 100). This calculation can overstate the importance of very small prey that can appear in extremely large numbers, but may be in small volume or only found in a few samples.

Index of Relative Importance (IRI): IRI is a compound index that takes into account both the number of samples in which a particular prey type was found (% FO) and the number of individuals of that prey type (% NA) found across all samples. For each prey type, IRI is calculated as follows (Liao et al., 2001):

$$IRI = \% FO (\% W + \% NA)$$

"W" is the total wet weight of prey in a unit. But because the analysis of monk seal diet is from remains in fecal samples, we do not have weight of the prey, so we assumed that weight was constant for all prey items (i.e., % W = 1), and used % FO and % NA to calculate IRI. Given that monk seals generally eat food items similar to the width of their head or smaller (and given that we have no other physical data regarding size or mass of prey), the assumption of food items being constant is not unreasonable. We then calculated the relative proportion of consumption of each prey type as "percent index of relative importance" (% IRI), which is equal to the IRI for a certain prey type divided by the sum of IRI values for all prey types (multiplied by 100).

2.3.3 Overlap of Monk Seal Diet and Commercial Fisheries Landings

There were 32 families of fishes and other animals represented in the Hawaiian monk seal diet or in commercial or recreational fishery data (Fig. 3, Table 11). These include 22 families identified in the Hawaiian monk seal diet, 7 of which were targeted only by monk seals (comprising 2% of the monk seal IRI), with no landings reported in commercial or recreational fisheries (Table 12).

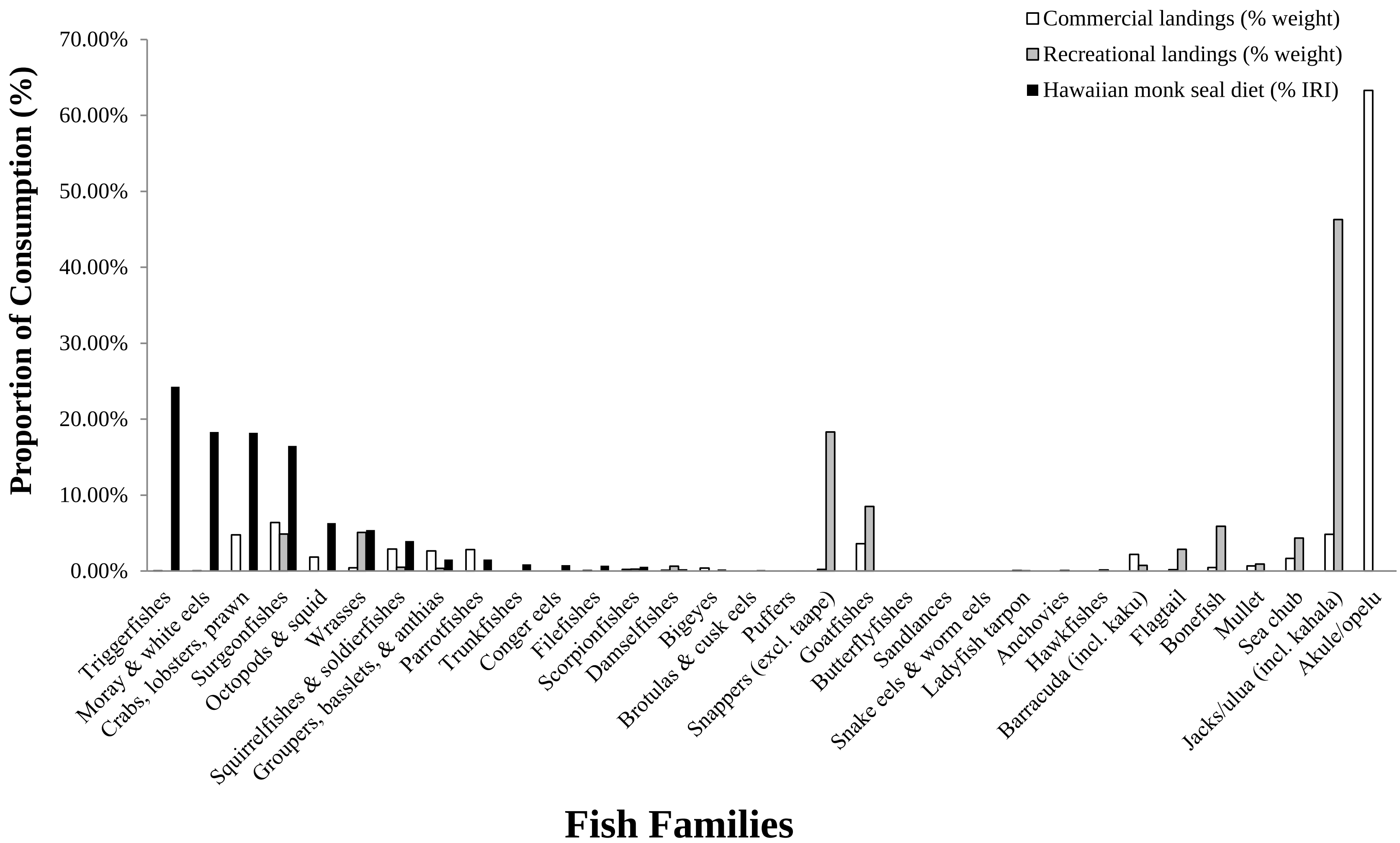

Figure 3.--Relative proportion of consumption of all fish families found in Hawaiian monk seal diet, commercial fisheries or recreational fisheries.

Table 11.--Prey groups found in commercial fishery and recreational fishery landings and in Hawaiian monk seal diet in the MHI. Relative proportion of consumption of a prey group is expressed as % Index of Relative Importance (% IRI) for monk seals, and as % total landed weight for commercial and recreational fisheries (excluding pelagic species and recreational catch from > 3 miles from shore).

Family	**Common Name**	**Commercial Landings (% Weight)**	**Recreational Landings (% Weight)**	**Hawaiian Monk Seal Diet (% IRI)**
Balistidae	Triggerfishes	0.04	0	24.30
Muraenidae/ Congridae	Moray & white eels	0.03	0	18.32
Crustacean	Crabs, lobsters, prawn	4.79	—	18.23
Acanthuridae	Surgeonfishes	6.38	4.89	16.50
Cephalopod	Octopods & squid	1.86	—	6.34
Labridae	Wrasses	0.42	5.08	5.40
Holocentridae	Squirrelfishes & soldierfishes	2.89	0.49	3.97
Serranidae	Groupers, basslets, & anthias	2.68	0.36	1.52
Scaridae	Parrotfishes	2.83	—	1.52
Ostraciidae	Trunkfishes	—	—	0.90
Congridae	Conger eels	—	0	0.79
Monacanthidae	Filefishes	0.08	0	0.73
Scorpaenidae	Scorpionfishes	0.22	0.26	0.58
Pomacentridae	Damselfishes	0.13	0.66	0.27
Priacanthidae	Bigeyes	0.40	—	0.23
Ophidiidae	Brotulas & cusk eels	—	0	0.14
Tetraodontidae	Puffers	—	—	0.08
Lutjanidae	Snappers (excl. taape)	0.21	18.32	0.08
Mullidae	Goatfishes	3.61	8.53	0.04
Chaetodontidae	Butterflyfishes	—	0	0.04
Ammodytidae	Sandlances	—	—	0.04
Ophichthidae	Snake eels & worm eels	—	0	0.01
Elopidae	Ladyfish tarpon	0.07	0.05	—

Table 11 *continued*

Family	**Common Name**	**Commercial Landings (% Weight)**	**Recreational Landings (% Weight)**	**Hawaiian Monk Seal Diet (% IRI)**
Engraulidae	Anchovies	—	0.07	—
Cirrhitidae	Hawkfishes	—	0.14	—
Sphyraenidae	Barracuda (incl. kaku)	2.21	0.77	—
Kuhliidae	Flagtail	0.20	2.88	—
Albulidae	Bonefish	0.46	5.92	—
Mugilidae	Mullet	0.67	0.95	—
Kyphosidae	Sea chub	1.67	4.35	—
Carangidae	Jacks/ulua (incl. kahala)	4.85	46.29	—
Carangidae	Akule/opelu	63.29	—	—

* Shading indicates the 15 prey families with overlap between Hawaiian monk seals and commercial fisheries.
** A zero (0) value indicates that the family was included in the data report, but catch weight was reported as zero. A dash (—) indicates that there were no data reported for that family from the data source.

Table 12.--Number of families (N) and relative importance of prey groups targeted only by fisheries, only by Hawaiian monk seals, or targeted by both fisheries and monk seals.

Prey Group Type	**N**	**Hawaiian Monk Seal % IRI**	**Fishery Landings % Weight**
Fishery Target Only	10		
Commercial	8	—	73.4
Recreational	9	—	61.4
Hawaiian Monk Seal Target Only	7	2.0	—
Targeted by Both	15		
Commercial & Seals	15	98.0	26.6
Recreational & Seals	8	28.4	38.6

There were 15 families that showed overlap between fisheries landings and monk seal diet (Fig. 4). These families represented 98% of the IRI in Hawaiian monk seal diet, but 26.6% of reported commercial fishery landings, and 38.6% of reported recreational fisheries (by weight, excluding pelagic species and recreational catch from > 3 miles from shore). Figure 4 shows the 15 overlapping families and their relative prevalence in fisheries (by weight) and in Hawaiian monk seal diet. There were 23 families reported in commercial fishery landings, excluding pelagic species. Of those, 8 families were only targeted by commercial fisheries (i.e., not found in Hawaiian monk seal diet). Landings in those 8 families made up 73.4% of the landed weight by commercial fisheries excluding pelagic species. There were 17 fish families reported with catch from recreational fisheries, excluding pelagic species, and all catch from > 3 miles from shore. Of those, 9 families were only targeted by recreational fisheries, making up 61.4% of the landed weight (Table 12).

Comparing overlap between Hawaiian monk seals and the total commercial and recreational fishery landings *including* pelagic species, 1.3% of the total commercial landed weight, and 3.4% of the recreational landed weight were from fish families that are also found in Hawaiian monk seal diet.

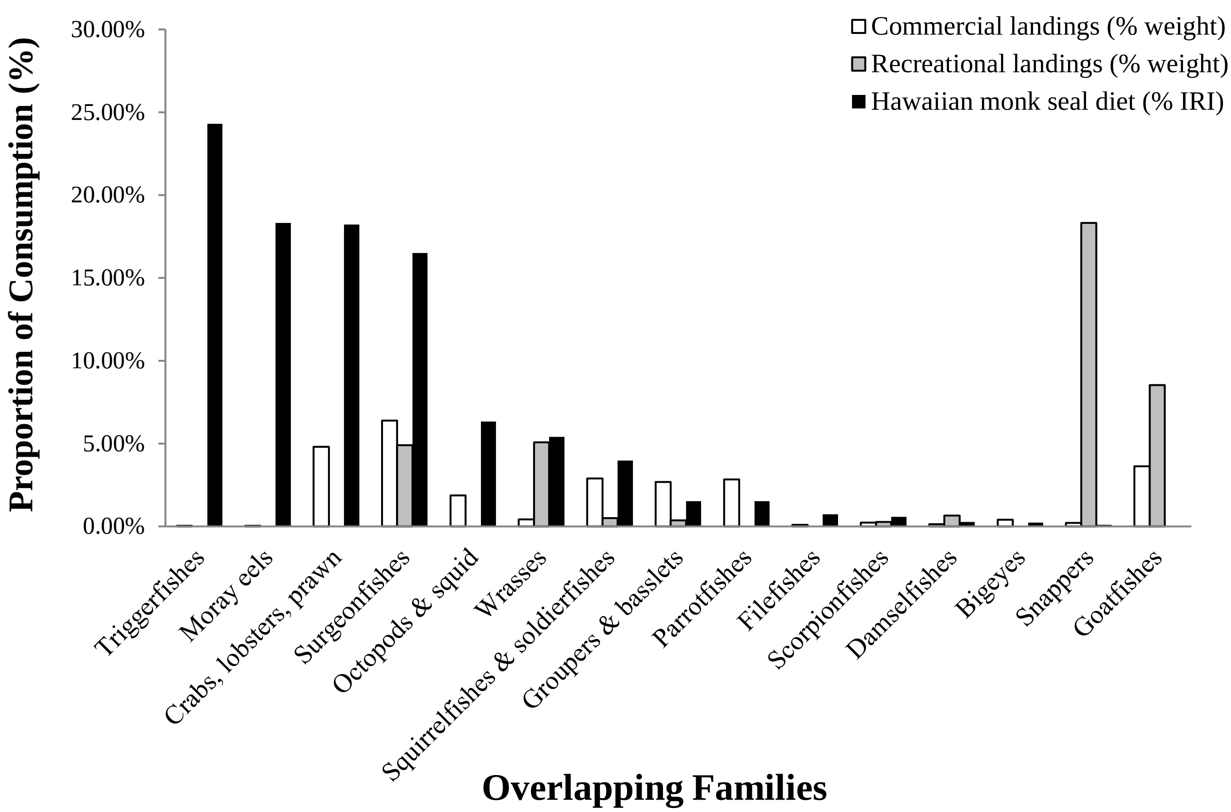

Figure 4.--Relative proportion of consumption of overlapping fish families in Hawaiian monk seal diet and in commercial and recreational fisheries.[6]

[6] Bars of uneven height do not imply differences in total biomass consumption of a given family. For instance, this graph does not show that monk seals eat more surgeonfishes by mass than fisheries catch. Rather, it shows that surgeonfishes make up about 16% of monk seal diet, relative to the other fish families that seals eat, and surgeonfishes make up about 5-6% of commercial and recreational fisheries relative to other fish families landed by fisheries.

Overall, Hawaiian monk seal diet and fisheries landings overlapped in 15 prey families. Those families make up 98% of the IRI in Hawaiian monk seal diet, but 27% of reported commercial fishery landings, and 39% of reported recreational fishery landings. More than 70% of commercial landings and more than 60% of recreational landings (by weight, excluding pelagic species) are fish not found in monk seal diet.

3 DISCUSSION

As the Hawaiian monk seal population has rebounded in the MHI, there has been increased resource use overlap between seals and humans. This has led to questions and concerns about impact of Hawaiian monk seals on the ecosystem and in particular, populations of marine species that are fished by humans. In this analysis, we estimated biomass consumption by the current Hawaiian monk seal population in the main Hawaiian Islands. To put this into context, we also estimated biomass removals by other apex fish predators and by commercial and recreational fisheries. Finally, we compared the species found in monk seal diet and those targeted by fisheries. We estimated that a current maximum assumed population of about 200 Hawaiian monk seals consumes around 1300 kg/day, which is a maximum of 0.009% of the available prey biomass. This estimate is based on a daily consumption rate of 4% of body weight for adults, 6% for subadults, and 8% for juveniles. These estimated consumption rates are similar to other studies estimating pinniped consumption at 2–6% of body weight per day (Innes et al., 1987; Perez and McAlister, 1993; Col et al., 2012). The recovery goal for Hawaiian monk seals in the main Hawaiian Islands is 500 individuals (NMFS, 2007). If the Hawaiian monk seal population reached 500 seals and there were no changes in standing biomass around the main Hawaiian Islands, they would consume at most ~ 0.013% of the minimum estimated available biomass daily.

The biomass of apex fish predators in the marine ecosystem around Hawaii is estimated to be more than 80 times the biomass of the Hawaiian monk seal population, and they likely consume at least 50 times as much biomass daily as do monk seals. Similarly, recreational and commercial fisheries are estimated to land at least ~ 3 times more than monk seals consume daily. At most, 27% of reported commercial fishery landings, and 39% of reported recreational fishery landings (by weight, excluding pelagic species) was made up of fish families also found in monk seal diet. We do not know whether individual species of fish consumed in those families by Hawaiian monk seals and by fisheries are similar.

3.1 Consumption in an Ecosystem Context

These findings are consistent with other studies showing that predation from marine mammals may be an order of magnitude lower than consumption by large predatory fish in various ecosystems (Trites et al., 1997; Overholtz and Link, 2006; Bundy et al., 2009). When examining the consumption of marine resources by other predators (be they piscivorous fish or marine mammals), it is tempting to think of a simple predator-prey relationship and a result that those consumed resources go from being available, to unavailable for fisheries to capture. However, this is an extremely simplistic and false comparison. Marine mammals eat diverse prey across many different species and over a large area, so have indirect and often complex effects in the ecosystem. It is important to remember that Hawaiian monk seals are opportunistic feeders, while fisheries are generally targeted toward specific species. When a seal eats a fish, it has an effect both on the prey and the competitors or predators of the prey. Consumption of one fish species by a seal may indirectly benefit another species. The secondary beneficial effects of marine mammal predation are generally more powerful than the negative effects of direct competition for a certain species (Morissette et al., 2009). Even when there is direct overlap of target species, marine mammals often prefer prey fish that are smaller than those of the same species recruited to the fishery (Perez and McAlister, 1993; Hammill et al., 1995; Olsen and Bjorge, 1995; Bowen and Siniff, 1999; Hammill and Stenson, 2000; Trzcinski et al., 2006).

Furthermore, when fish are harvested by humans, almost all of the associated nutrients are removed from the local marine ecosystem. However, consumption by marine mammals and other predatory fish redistributes nutrients, and may actually have a positive effect on overall biomass (Morissette et al., 2012). In simulated extirpations of marine mammals from modeled ecosystems, the overall biomass generally remained similar, or even decreased for some species (Morissette et al., 2012). When species or groups increased as a result of the simulated extirpation, these groups were not necessarily the most important commercially, and if they were, the system was often not in a stable equilibrium: while there may have been more fish to catch initially, once they were overfished, the ecosystem could become unstable and at risk of severe losses in biodiversity (Morissette et al., 2012). In an EcoSim model of the Caribbean ecosystem, commercially targeted fish biomass did not increase with eradication of whales, but a small decrease in fishing mortality led to considerable increases in fish biomass (Gerber et al., 2009). Overall, the evidence predominately indicates that even with direct competition, fisheries are more likely to affect marine mammals than the reverse (Yodzis, 2001; Gerber et al., 2009; Lindstrom et al., 2009). Even the complete eradication of all marine mammals, from all oceans, would likely not increase fisheries catches (Kaschner and Pauly, 2005; Morissette et al., 2012).

3.2 Ecosystem vs. Local Scale

In this analysis, we estimated Hawaiian monk seal consumption and compared it on a broad scale to the nearshore marine ecosystem around the main Hawaiian Islands. On this level, and given the diversity of monk seal diet, interactions between species are complex and there is little evidence that Hawaiian monk seals have a significant negative effect on any one species that exceeds the effects of other apex predators or human fisheries. However, there may be a difference between the broad scale effects addressed here, and localized impacts when a seal (or seals) engage in intensive foraging within a small area (e.g., less than 0.01 km^2). A seal could potentially alter prey abundance, at least temporarily, if it were foraging for some duration in a small area, and this could affect fishing opportunity on a short-term scale. Currently, there is little evidence, other than anecdotal reports, that declines in prey abundance in certain areas are a result of Hawaiian monk seal presence, rather than other marine predators, fishing, land-based sources of pollution, or environmental variability. Improved communication between NOAA Fisheries and local fishing communities, better reporting of subsistence and recreational fishery catch, and direct observation of Hawaiian monk seal foraging behaviors (e.g., using CritterCam) may help illuminate potential localized effects.

3.3 Data Limitations

We think that the calculations and estimates made in this analysis are reasonable, within the bounds of existing data, and in some cases are significant overestimates of potentially negative effects. There are several areas of the analysis that could be improved with more data.

Biomass

The estimates of marine ecosystem biomass around the main Hawaiian Islands have the most uncertainty and likely considerably underestimate the true available prey biomass over the area in which monk seals forage. The area calculation that we used from NOAA Fisheries CRED surveys only mapped habitat out to 30-m depth. This area is only about 12% of the area found in the 200-m depth contour around the main Hawaiian Islands, and we know that Hawaiian monk seals do many dives out to 200 m or deeper. We used this smaller area calculation because the fish density measurements available for the main Hawaiian Islands were only taken in the shallow reef area (< 30 m) and are not applicable to the deeper reef area.

As a result, the estimate of available prey biomass (and apex predator biomass) that we used for this analysis is significantly underestimated. This shallow area may be the primary area in which Hawaiian monk seals and fisheries overlap in resource use, so using the area < 30 m may be useful for attempts to understand localized impacts of Hawaiian monk seals on human fisheries. But by only calculating biomass for this area, and comparing that to the entire Hawaiian monk seal population consumption, we are assuming that Hawaiian monk seals do all of their foraging in this shallow area, rather than the much larger area that we know they utilize. Surveys of fish density, species composition and size composition in the deeper waters of the monk seal foraging range would enable more realistic estimates of prey (and apex predatory fish) biomass.

Consumption

As discussed above, direct comparisons of Hawaiian monk seal consumption to available biomass or fishery landings are overly simplistic and logically problematic. But for the purposes of this discussion, and based on the choices we made in the data sets used, we think that the assessments of Hawaiian monk seal consumption in relation to available biomass is a significant overestimate. We have confidence in the estimate of Hawaiian monk seal population size, biomass, and consumption, but more information about average body mass of seals in the main Hawaiian Islands and the caloric value of prey would help us further refine these calculations.

Overlap Between Hawaiian Monk Seal Diet and Fisheries

Finally, data on fishery landings and species targeted are very limited. While there is required reporting for commercial fishermen, there is no saltwater fishing license for recreational or subsistence fishing, and no requirement for these fishermen to report their catch. Data on the catch and landings by recreational and subsistence fishermen are derived from voluntary surveys, and use of the data is hampered by various problems including possible underreporting, survey location bias, and small sample size. Based on currently available data, it appears there is a not a high degree of overlap between Hawaiian monk seal diet and human fisheries. We are able to make some comparisons, but it is possible that there are gaps in the reported species taken in the recreational fishery. For instance, there is no recreational catch reported for octopus or parrotfish, species highly sought by recreational and subsistence fishermen. Improved data collection regarding species and amount landed in the recreational and subsistence fisheries would allow us to refine our calculations of the overlap with Hawaiian monk seal diet and potential impacts.

The current techniques for characterization of Hawaiian monk seal diet only allow identification down to the level of families, not species. So while we have described that some *families* of fishes may be targeted by both fishermen and monk seals, it is possible that the actual *species* consumed by seals and fishers within those families may not overlap. Furthermore, even if there is direct competition between fisheries and monk seals for the same species, there may be divergence in the size of the individuals, the area, and the depth over which those species are taken (Perez and McAlister, 1993; Hammill et al., 1995; Olsen and Bjorge, 1995; Bowen and Siniff, 1999; Hammill and Stenson, 2000; Trzcinski et al., 2006)

There are a number of areas where improvements in the quality and quantity of data available may help us refine this analysis in the future. Obtaining more data in some of these areas will require substantial changes, such as in how the State of Hawai`i and NOAA Fisheries collect fisheries data and in the communications between NOAA Fisheries researchers and fishermen reporting interactions.

3.4 Future Directions

In addition to changes in data collection and fishery reporting, NOAA Fisheries can move forward immediately with research from the perspective of Hawaiian monk seals. In 2012, the Pacific Islands Fisheries Science Center began a 3-year project to deploy cameras on Hawaiian monk seals. The cameras will allow researchers to view and analyze how seal behavior differs across habitats and depths, and potentially see interactions with humans and fisheries from the seal's perspective. This study may be able to add a further level of validation to our assessment of monk seal consumption by directly viewing the rate and relative size of prey captures and enabling us to estimate biomass consumption by different seals. This would allow future analyses of monk seal consumption to use observed wild monk seal consumption measurements, an improvement over using data from captive monk seals or models. The cameras (with associated GPS tags) may allow researchers to add a spatial component to consumption as well (e.g., how much a seal eats over a certain area) to improve assessments of the relative consumption occurring in different habitats or depths, and potential impact of monk seals on an ecosystem scale vs. a local scale. In this way, the analysis here can be seen as presenting testable hypotheses for empirical studies of seals in the field (e.g., necessary capture rate of food items in order to consume a given amount of biomass per day). NOAA Fisheries will continue to work with fishermen and our state and nongovernment partners to advance our understanding of marine species impacts on humans and vice versa.

3.5 Conclusions

Our analysis estimated that Hawaiian monk seals consume marine resources in the MHI at a level that is at least 50 times less than the biomass consumed by other apex predator fish and about 3 times less than landings by commercial and recreational fisheries. We do not find any support for assertions that Hawaiian monk seals have a significant ecosystem-level impact on the marine resources or fisheries in the main Hawaiian Islands. Current data are insufficient to address the potential effects of seals on a small localized area (e.g., a singular bay, particular fishing spot, etc.), but ongoing studies with direct observation of Hawaiian monk seal foraging behaviors will help answer these questions. There are still several areas where available data can be improved. NOAA Fisheries will continue to revisit this analysis in the future as conditions and information change.

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Appendix A – Values Used for Energy Consumption Calculations

Table A-1.--Values used for energy consumption (*C*) calculations (from Innes et al. 1987).

Taxon	**Maturity**	**Energetic State**	*n*	*a*	*b*	R^2
Phocidae	Adult	Maintenance & Growing	24	5.07	0.80	0.91
Phocidae	Subadult & Juvenile	Growing	23	24.1	0.57	0.52
Pinniped	Juvenile	Growing	30	28.9	0.52	0.42
Terrestrial Carnivora	Juvenile	Growing	32	13.6	0.52	0.42

Appendix B – Commercial Fishery Landing Data Summary

Table B-1.--Commercial fishery landings reported to the State of Hawai`i DLNR from 2003 to 2009 (DLNR, 2003, 2004, 2005, 2006, 2007, 2008, 2009). All are sea landings reported in pounds (lbs). Families marked as "excluded" were not included in the analysis of biomass consumption (Section 2.5).

Family	Common Name	2003	2004	2005	2006	2007	2008	2009	Annual Average (lbs)	Daily Average (lbs)	Daily Average (kg)
Acanthuridae	Surgeonfishes	102,703	88,448	90,018	71,984	76,637	81,094	88,044	85,561	234	106
Albulidae	Bonefish	3,057	2,002	3,344	5,175	9,822	11,308	8,531	6,177	17	8
Balistidae	Triggerfishes	62	113	61	8	236	812	2,015	472	1	1
Carangidae	Akule/`opelu	847,465	1,002,718	887,225	867,448	1,094,462	620,770	617,268	848,194	2,324	1,054
Carangidae	Jacks/ulua (incl. kahala)	82,304	84,383	58,442	39,480	70,828	61,079	58,347	64,980	178	81
Cephalopod	Octopods & squid	25,864	23,108	20,956	20,434	18,290	31,305	34,335	24,899	68	31
Crustacean	Crabs, lobsters, prawn	40,138	34,402	150,892	36,589	52,190	57,557	77,921	64,241	176	80
Elopidae	Ladyfish tarpon	823	430	581	1,106	1,407	408	1,642	914	3	1
Holocentridae	Squirrelfishes & soldierfishes	34,548	29,629	35,367	24,041	36,049	59,171	52,508	38,759	106	48
Kuhliidae	Flagtail	2,995	1,893	2,250	1,266	1,670	4,182	4,180	2,634	7	3
Kyphosidae	Sea chub	19,503	19,349	19,639	35,616	26,773	21,597	14,479	22,422	61	28
Labridae	Wrasses	6,532	6,094	3,761	4,965	4,611	6,026	7,645	5,649	15	7
Lutjanidae	Snappers (excl. taape)	1,789	3,387	1,851	2,433	2,645	3,460	4,223	2,827	8	4
Monacanthidae	Filefishes	906	3,590	407	741	595	454	994	1098	3	1
Mugilidae	Mullet	9,239	8,171	7,785	8,369	11,329	9,740	8,560	9,028	25	11
Mullidae	Goatfishes	62,201	68,994	39,703	40,348	35,499	38,055	54,193	48,428	133	60
Muraenidae	Moray & white eels	59	124	85	101	250	483	1,864	424	1	1
Pomacentridae	Damselfishes	908	1,745	2,131	2,085	1,240	1,867	1,882	1,694	5	2
Priacanthidae	Bigeyes	3,209	14,117	5,541	2,987	4,842	3,843	2,752	5,327	15	7
Scaridae	Parrotfishes	35,506	32,049	32,573	30,387	40,094	44,806	50,475	37,984	104	47
Scorpaenidae	Scorpionfishes	3,348	2,972	3,279	2,713	2,303	2,053	3,641	2,901	8	4
Serranidae	Groupers, basslets, & anthias	49,052	44,292	48,214	31,443	29,203	23,226	25,742	35,882	98	45
Sphyraenidae	Barracuda (incl. kaku)	24,881	35,580	30,260	32,526	26,976	34,964	22,005	29,599	81	37
-	Misc. inshore fishes (incl. moi, mu, awa)	5,304	4,054	5,499	5,154	11,156	15,346	15,752	8,895	24	11
Subtotal		**1,362,396**	**1,511,644**	**1,449,774**	**1,267,399**	**1,559,107**	**1,133,606**	**1,158,998**	**1,348,989**	**3,969**	**1,676**

Table B-1 (continued).--Commercial fishery landings reported to the State of Hawai`i DLNR from 2003 to 2009. All are sea landings reported in pounds (lbs). Families marked as "excluded" were not included in the analysis of biomass consumption (Section 2.5).

Family	Common Name	2003	2004	2005	2006	2007	2008	2009	Annual Average (lbs)	Daily Average (lbs)	Daily Average (kg)
EXCLUDED											
Istiophoridae & Xiphiidae	Billfishes & swordfishes	3,029,870	2,294,177	4,655,440	4,038,122	5,470,247	6,406,085	5,967,862	4,551,686	12,470	5,656
Scombridae	Tunas	14,055,058	13,315,002	14,596,986	12,618,034	18,660,259	18,908,288	15,229,305	15,340,419	42,029	19,064
-	Corals	0	0	0	0	3,775	0	0	539	1	1
Lutjanidae, Serranidae, Berycidae, Carangidae	Deep bottomfishes (excl. kahala)	503,002	557,875	465,096	438,035	437,880	448,054	473,573	474,788	1,301	590
-	Misc. pelagic fishes (excl. kaku)	4,085,433	4,600,925	4,377,301	4,266,075	4,686,313	4,816,942	5,211,042	4,577,719	12,542	5,689
-	Other animals (e.g. sea cucumber, limpet)	11,730	8,441	7,231	10,246	7,499	10,517	22,649	11,188	31	14
-	Seaweeds and limu	13,304	16,906	10,184	5,102	5,741	9,900	10,402	10,220	28	13
-	Sharks	203,253	142,289	193,450	177,205	370,349	337,043	297,078	245,810	673	305
-	Unclassified or misc	10,058	12,267	15,605	57,603	5,821	17,216	5,129	17,671	48	22
Subtotal		**21,911,708**	**20,947,882**	**24,321,293**	**21,610,422**	**29,647,884**	**30,954,045**	**27,217,040**	**25,230,039**	**69,123**	**31,354**
TOTAL		**23,274,104**	**22,459,526**	**25,771,067**	**22,877,821**	**31,206,991**	**32,087,651**	**28,376,038**	**26,579,028**	**72,819**	**33,030**

Appendix C – Recreational Fishery landing Data Summary

Table C-1.--Marine Recreational Information Program Query (NOAA Marine Recreational Fishing Survey Statistics (MRFSS) website, http://www.st.nmfs.noaa.gov/recreational-fisheries/access-data/run-a-data-query/queries/index, data extracted November 13, 2012).

Query Parameter	**Output**
Query	MRIP CATCH SNAPSHOT
Year	2003-2011
Wave	ANNUAL
Geographic Area	HAWAII
Fishing Mode	ALL MODES COMBINED
Fishing Area	ALL AREAS BY AREA
Type of Catch	ALL CATCH TYPES
Information	WEIGHT OF FISH

Table C-2.--Recreational fishery landings reported in the Hawai`i Marine Recreational Fishing Survey from 2003 to 2011. All are landings from shore or from < 3 miles from shore reported in pounds (lbs). Families marked as "excluded" were not included in the analysis of biomass consumption (Section 2.5).

Family	Common Name	2003	2004	2005	2006	2007	2008	2009	2010	2011	Annual Average (lbs)	Daily Average (lbs)	Daily Average (kg)
Abulidae	Bonefishes	8,508	259,526	60,409	214,624	38,330	97,764	88,143	40,675	29,288	93,030	255	116
Acanthuridae	Surgeonfishes	135,661	73,859	158,062	87,556	7,676	7,906	23,473	85,519	111,922	76,848	211	96
Balistidae & Monacanthidae	Triggerfishes & filefishes	0	0	0	0	0	0	0	0	0	0	0	0
Carangidae	Jacks	605,420	863,082	873,702	1,696,371	334,223	716,651	407,169	489,651	562,817	727,676	1,994	904
Chaetodontidae	Butterflyfishes	0	0	0	0	0	0	0	0	0	0	0	0
Cirrhitidae	Hawkfishes	0	2,546	11,158	3,565	1,858	0	0	1,012	0	2,238	6	3
Clupeidae	Herrings	0	0	0	0	0	0	0	0	0	0	0	0
Elopidae	Tarpon	0	0	0	4,658	0	0	0	0	0	776	2	1
Engraulidae	Anchovies	8,433	503	0	0	0	0	0	0	0	1,117	3	1
Holocentridae	Squirrelfishes & soldierfishes	15,708	0	3,519	6,376	2,480	25,058	0	14,531	2,039	7,746	21	10
Kuhliidae	Flagtails	176,581	29,778	69,080	75,246	10,615	32,304	5,551	5,390	3,219	45,307	124	56
Kyphosidae	Sea chubs	587,756	4,751	8,684	1,274	0	0	0	0	13,543	68,445	188	85
Labridae	Wrasses	137,096	226,437	186,500	86,192	22,002	529	0	41,469	18,402	79,847	219	99
Lutjanidae	Snappers	276,744	701,001	358,224	189,597	247,991	201,178	105,147	352,662	159,418	287,996	789	358
Mugilidae	Mullets	13,880	47,723	2,809	1,933	6,243	0	0	52,366	8,836	14,866	41	18
Mullidae	Goatfishes	250,189	360,749	75,621	189,917	134,687	70,610	32,950	77,173	14,630	134,058	367	167
Muraenidae,Ophich-thidae, Ophidiidae, Congridae	Eels	0	0	0	0	0	0	0	0	0	0	0	0
Pleuronectidae	Flounders	0	0	0	0	0	0	0	0	0	0	0	0
Pomacentridae	Damselfishes	3,929	22,053	26,797	29,974	8,159	1,823	0	0	0	10,304	28	13
Scorpaenidae	Scorpionfishes	4,253	3,239	10,364	1,186	6,303	5,873	0	1,422	0	4,080	11	5
Serranidae	Sea basses	16,583	3,316	10,776	7,582	4,458	0	0	825	7,835	5,708	16	7
Sphyraenidae	Barracudas	15,130	45,349	26,599	1,894	0	9,319	4,850	2,996	2,518	12,073	33	15
Tetraodontidae	Puffers	0	0	0	0	0	0	0	0	0	0	0	0
-	Other fishes	1,232	197,979	1,225,586	94,192	7,485	5,313	11,713	35,428	45,219	180,461	494	224
Subtotal		**2,257,103**	**2,841,890**	**3,107,888**	**2,692,139**	**832,511**	**1,174,328**	**678,997**	**1,201,119**	**979,687**	**1,752,576**	**4,802**	**2,178**
EXCLUDED													
Coryphaenidae	Mahimahi	757,212	274,801	310,547	416,585	313,067	240,116	223,562	85,976	117,023	304,321	834	378
Scombridae	Tunas & mackerels	4,195,789	932,788	1,071,461	656,714	458,733	558,609	774,013	880,979	481,632	1,112,302	3,047	1,382
-	Sharks	0	0	0	0	0	0	0	0	0	0	0	0
Subtotal		**4,953,001**	**1,207,589**	**1,382,008**	**1,073,299**	**771,800**	**798,725**	**997,575**	**966,955**	**598,656**	**1,416,623**	**3,881**	**1,760**
TOTAL		**7,210,104**	**4,049,479**	**4,489,896**	**3,765,438**	**1,604,311**	**1,973,053**	**1,676,572**	**2,168,074**	**1,578,343**	**3,169,199**	**8,683**	**3,938**

Table C-3.--Recreational fishery landings from > 3 miles from shore reported in the Hawaii Marine Recreational Fishing Survey. All landings are reported in pounds (lbs). These landings were not included in analyses for this paper, but are included for reference.

Family	Common Name	2003	2004	2005	2006	2007	2008	2009	2010	2011	Annual Average (lbs)	Daily Average (lbs)	Daily Average (kg)
Abulidae	Bonefishes	0	0	0	17,269	0	0	0	0	0	1,919	5	2
Acanthuridae	Surgeonfishes	0	0	450	0	712	0	0	0	0	129	0	0
Balistidae & Monacanthidae	Triggerfishes & filefishes	0	0	0	0	0	0	0	0	0	0	0	0
Carangidae	Jacks	17,009	75,230	75,945	85,561	15,324	36,299	54,802	10,465	12,661	42,589	117	53
Coryphaenidae	Mahimahi	1,002,685	4,247,586	2,748,107	3,957,438	2,261,687	3,173,061	1,673,979	2,438,288	1,023,325	2,502,906	6,857	3,110
Holocentridae	Squirrelfishes & soldierfishes	0	0	0	0	0	0	0	0	0	0	0	0
Kyphosidae	Sea chubs	0	0	0	0	0	0	0	0	0	0	0	0
Labridae	Wrasses	1,651	0	1,281	5,384	549	0	0	0	1,636	1,167	3	1
Lutjanidae	Snappers	98,957	88,967	191,030	97,524	63,449	15,721	45,894	207,653	73,941	98,126	269	122
Mugilidae	Mullets	0	0	0	0	0	0	0	0	0	0	0	0
Mullidae	Goatfishes	346	2,004	1,722	295	3,371	0	1,409	1,828	5,922	1,877	5	2
Muraenidae, Ophichthidae, Ophidiidae, Congridae	Eels	0	0	0	0	0	0	0	0	0	0	0	0
Scombridae	Tunas & mackerels	11,759,311	8,162,372	8,412,113	9,193,287	14,032,781	21,005,597	17,756,719	10,712,734	8,813,211	12,205,347	33,439	15,168
Scorpaenidae	Scorpionfishes	0	0	0	0	0	0	0	0	0	0	0	0
Serranidae	Sea basses	0	0	0	0	0	0	3,161	15,503	0	2,074	6	3
Sphyraenidae	Barracudas	0	11,039	5,518	0	0	0	0	3,708	0	2,252	6	3
-	Sharks	0	0	0	0	0	0	0	0	0	0	0	0
-	Other fishes	985,853	1,265,344	3,027,999	525,487	101,088	1,691,235	480,336	241,668	149,352	940,929	2,578	1,169
TOTAL (catch >3 miles from shore)		**12,879,959**	**12,587,199**	**11,436,166**	**13,356,759**	**16,377,873**	**24,230,679**	**19,535,965**	**13,390,178**	**9,930,695**	**14,858,386**	**40,708**	**18,465**
Total catch < 3 miles (from Table C-2)		**7,210,104**	**4,049,479**	**4,489,896**	**3,765,438**	**1,604,311**	**1,973,053**	**1,676,572**	**2,168,074**	**1,578,343**	**3,169,199**	**8,683**	**3,938**
GRAND TOTAL RECREATIONAL CATCH		**20,090,063**	**16,636,678**	**15,926,062**	**17,122,197**	**17,982,184**	**26,203,732**	**21,212,536**	**15,558,252**	**11,509,038**	**18,027,585**	**49,391**	**22,403**

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