

**Initial Defecation Time and Rate of Passage of Digesta in Adult Hawaiian Monk Seals,
*Monachus schauinslandi***

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Abstract

In an effort to gain a better understanding of the digestive physiology of the Hawaiian monk seal, *Monachus schauinslandi*, we measured the initial defecation time and rate of digesta passage using chromic oxide (Cr_2O_3) and frozen corn kernels as markers. IDT ranged from 9.5 to 19 h (mean 14 ± 4.8 h), which was a longer period of time than that reported for any other pinniped. Rate of digesta passage using a single pulse dose of Cr_2O_3 was approximately 39 h for two of the three seals, which is also longer than that reported for other pinnipeds. Possible reasons for these longer rates include morphological and physiological differences, age of the seals, and feeding regime. Percent Cr_2O_3 recovery was low (52.7-74.8%), reflecting the difficulty in collecting liquid stools. Levels of protein and ash (dry matter basis) were 21.70 and 34.79% respectively, which reflects the high protein and mineral content of the herring diet. This study has provided essential baseline data that will provide further insight into the digestive physiology of the Hawaiian monk seal.

Introduction

The feeding ecology of pinnipeds is complex and requires knowledge of the animal's natural prey, along with comprehension of its digestive physiology. Partial understanding of this physiology may be accomplished by measuring both the initial defecation time (IDT) and rate of passage of digesta in the animal. The IDT, also reported as transit time, refers to the elapsed time that occurs between ingestion of a marked meal and its first appearance in the feces (Helm 1984). Rate of passage refers to the time required for the entire marked meal to pass through a point in the digestive tract in a given time (Kotb and Luckey 1972). Both of these methods require continuous collection of the feces along with records of the precise timing of defecation of the marker and give rise to a cumulative excretion curve with a sigmoid shape. Rate of digestion and assimilation efficiency studies have been conducted on a variety of terrestrial animals including bobcats (Golley et al. 1965), lizards (Nagey 1977) and birds (Speakman 1987), where collection of feces is straightforward. However, collection of feces from aquatic species is difficult, and this may be reflected by the relatively few rate of passage studies conducted on pinnipeds. From the few studies concerning IDT or transit times and digestion rates (Helm 1984; Markussen 1993; Krockenberger and Bryden 1994), it is apparent that both of these parameters are affected by multiple variables such as length of the gastrointestinal tract, metabolic rate, frequency of feeding, and activity level, and may also be species or diet specific.

Studies on prey preferences of pinnipeds commonly use either stomach content analysis and (or) analysis of prey remains from fecal samples collected on land. The distance offshore to which the animals are foraging, combined with their rates of digestion, will directly affect the composition of the samples that are used for prey preference studies. Thus, rate of passage of digesta studies are needed to validate foraging studies, especially in Hawaiian monk seals, which have been shown to forage several kilometers offshore for at least several days at a time (DeLong et al. 1984). The purpose of the present study was to determine both the transit time and the rate of passage of digesta for the Hawaiian monk seal in captivity. These results are critical, since all monk seals (genus *Monachus*) are highly endangered or extinct. The present study will provide the basis for understanding future studies concerning the assimilation efficiencies of natural prey, along with information concerning the biases associated with foraging studies conducted on the Hawaiian monk seal.

Materials and Methods

Three adult male Hawaiian monk seals (*Monachus schauinslandi*) held at the Waikiki Aquarium, Oahu, Hawaii, were used for this study. These seals have been in captivity between 8 and 12 years and range in age from approximately 11 to 16 years. Annual veterinary physical examinations showed that they were in good health. All seals were cared for in accordance with the both the U.S. and Canadian Councils on Animal Care. The seals were fed 2500 g of frozen Pacific herring (*Clupea harengus*) once a day at 1000. It was bought in 40 lb lots and kept at -20 °C until it was thawed prior to feeding.

Two studies were conducted to determine the IDT. In the first experiment, chromic oxide (Cr_2O_3 ; Fisher Scientific, Fairlawn, N.J.) at 0.3% of the daily diet dry weight was placed in gelatin capsules and inserted into the herring's opercular cavities. The seals had been fed their normal diet consisting of a mixture of herring and capelin prior to this study to ensure a full digestive tract. It was not possible to collect the feces from anything but a drained tank. Therefore, for this experiment, the three seals were simultaneously fed one pulse each of chromic oxide via dosed herring from 1000 to 1045 and were then held within a drained tank for 40 h. During this period the seals were under constant observation and were wetted every 15 minutes to maintain thermoregulation.

Because these seals were not exposed to their normal level of swimming activity, a second IDT study was conducted where the seals had complete access to water. Since the seals most often defecated in the water at night, it was not feasible to use a marker that would disperse in water. Therefore, frozen corn kernels (human consumption grade) were used, since they are essentially indigestible by carnivores. They also float once they have passed through the digestive system, making them observable in the seal pool. For this second IDT experiment, 10 frozen corn kernels were placed directly within the opercular cavities of each seals' daily herring ration.

IDT was measured as the total elapsed time that occurred between the mid-point of the feeding time (0 h) and the first appearance of the marker. Activity of the seals was recorded on an hourly basis and the tank was inspected for fecal material every 15 minutes throughout the 40 h period for both experiments.

To measure the rate of passage of digesta in these seals, the time required for the chromic oxide to completely pass through the digestive tract was determined as the total elapsed time that occurred between the mid-point of the feeding time (0 h) and the last appearance of the marker. All feces were collected over a 40 h period and defecation times were recorded. Because these seals excreted a liquid-type stool, it was necessary to use absorbent paper towels to ensure maximal collection of the feces. Numbers of paper towels used were recorded and towels from the same batch were analyzed to determine their contribution (total weight of feces collected, % ash and % protein) to the fecal samples. Fecal samples and towels were dried at 50°C in a mechanical convection oven and ground through a 2 mm stainless steel screen in a Wiley mill. For each fecal sample that was collected from the three seals, duplicate subsamples were analyzed for chromic oxide (Hill and Anderson 1958), percent ash and Kjeldall protein (Association of Official Analytical Chemists 1990). Mean and standard deviation for these duplicate subsamples are reported.

Results

Over 40 h, each seal defecated between three to seven times, the difference being due mainly to individual variation. The IDTs tested ranged from 9.5 to 19 h (Cr_2O_3 marker 14 ± 4.8 h (mean \pm SD)) for the seals without access to water, and occurred within 10 to 21 h (corn kernel marker) for those seals with constant access to water. Chromic oxide excretion over time exhibited a bell-shaped fecal concentration curve for all three seals, with the peak concentration occurring between 13.5 and 19 h (mean = 17 ± 3 h; Fig. 1). No chromic oxide was found in the feces of seals 1 and 2 at the 39-h sampling time; seal 3 did not defecate between 26 and 40 h, so an endpoint for this seal was not observed (Fig. 1). Percent Cr_2O_3 recovery from the three seals ranged from 52.7 to 74.8 ($67 \pm 12\%$; Table 1).

Percent protein in individual fecal dry matter samples from the three seals was variable (21.70 ± 6.45 ; range = 14-33%; Table 1). For seals 1 and 2, the maximum concentrations were at 13.5 h, followed by a gradual decline (Fig. 2a). Seal 3 showed a different pattern of protein excretion with the maximum concentration occurring in the last sample at 39 h; however, because the fecal samples for this seal were limited in size, there was only enough material to conduct two protein assays rather than three (Fig 2a). Percent ash in individual fecal dry matter samples from the three seals also was variable (34.79 ± 11.09 ; range = 13-51%; Table 1). The excretion pattern followed the same trend as the chromic oxide excretion with lower values in the beginning and end of the test period, along with slightly increased concentrations occurring between 17.75 and 23.75 h for the three seals (Fig. 2b).

Table 1. Recovery of chromic oxide (Cr_2O_3) and level of dietary protein and ash in feces excreted over 40 h by 3 adult male Hawaiian monk seals. Recovery of Cr_2O_3 is expressed as percent of the total mass of Cr_2O_3 fed. Mean protein and ash are expressed as percentages of the mass of dry matter in the diet over the 40 h collection period.

Seal #	Cr_2O_3 Recovery (%)	Protein (% of dry matter)	Ash (% of dry matter)
1	72.2	23.04 \pm 6.15	28.42 \pm 8.10
2	52.7	19.97 \pm 5.62	42.57 \pm 8.99
3	74.8	17.81 \pm 4.78	40.31 \pm 6.80
x \pm SD	66.6 \pm 12.1	21.70 \pm 6.45	34.79 \pm 11.09

Figure 1. Mean concentration of chromic oxide (mg/g dry matter) in the feces of Hawaiian monk seals. Chromic oxide was fed to the seals at 0 hours, which was the mid point of the feeding period from 1000 to 1045. Vertical bars = 1 SD based on 2 replicates for each sample analyzed.

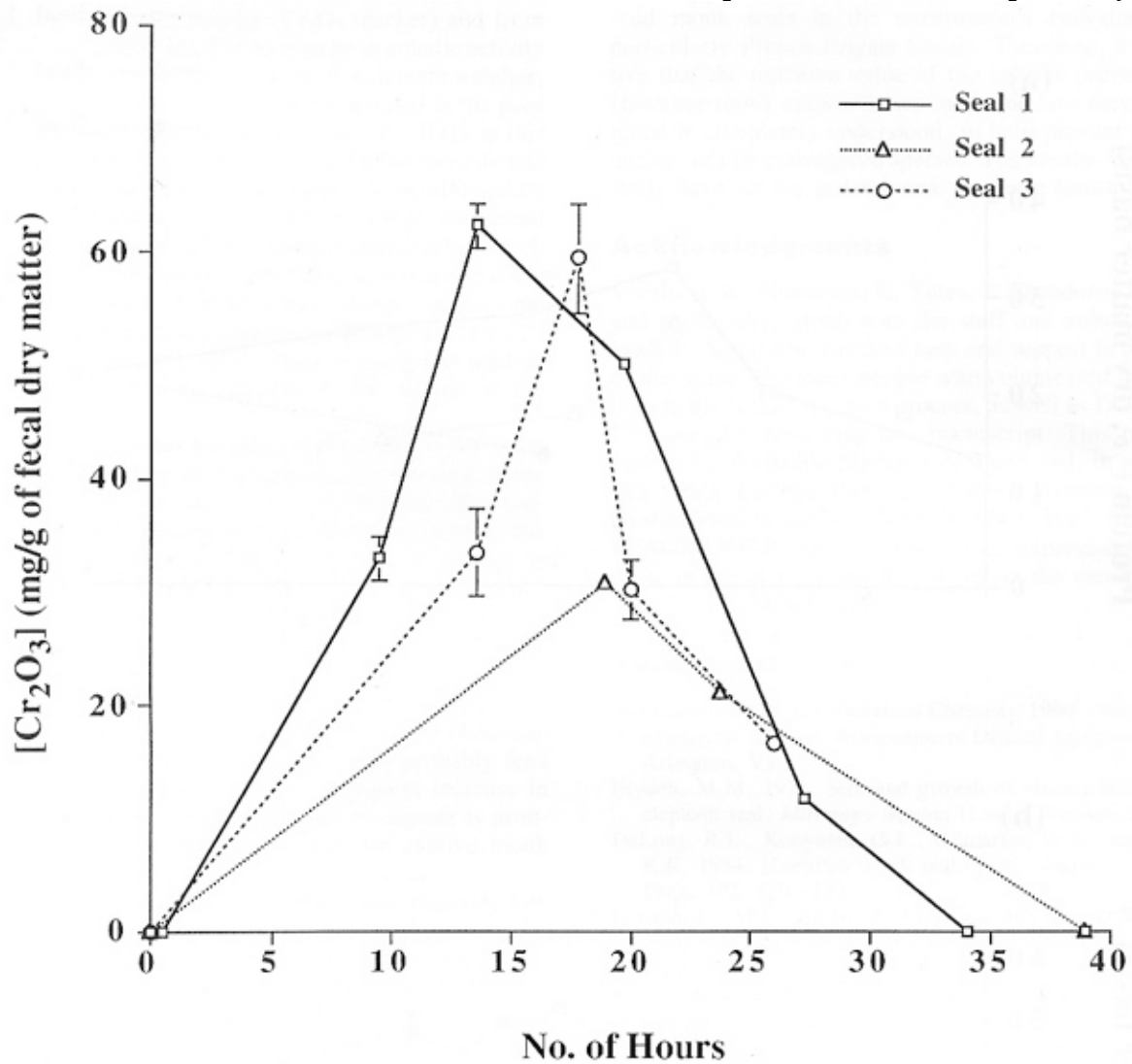
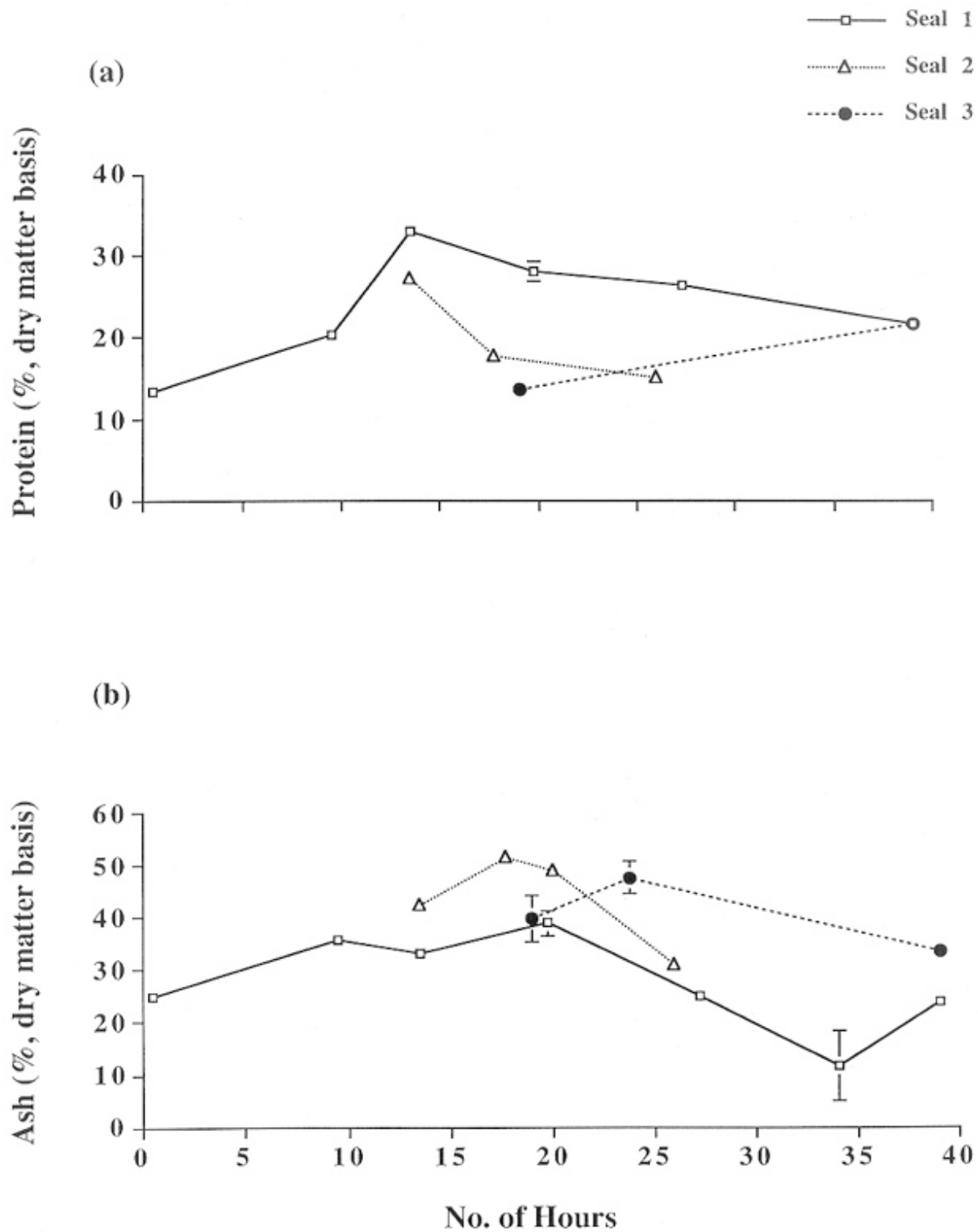


Figure 2. Mean concentration (% dry matter basis) of (a) protein and (b) ash in the feces of Hawaiian monk seals fed 2500 g of herring per day at 0 hours, which was the mid point of the feeding period from 1000 to 1045. Vertical bars = 1 SD based on 2 replicates for each sample analyzed. Standard deviation was too small to be detected where no error bars are visible.



Discussion

In previous studies conducted with pinnipeds, the length of the gastrointestinal tract, metabolic rate, activity level and the even energy content of the prey have been shown to affect the rate of digestion. Helm (1984) measured the IDT as an indicator of the digestion rate in northern elephant seals (*Mirounga angustirostris*), harbor seals (*Phoca vitulina richardsi*), and California sea lions (*Zalophus californianus*) using both ferric oxide and chromic oxide. He found that the mean IDT for all three species of pinnipeds occurred in 5 h or less. This transit time is considered extremely fast for a carnivore with one of the highest small intestine to body length ratios in the animal kingdom (25:1 for the elephant seal (Bryden 1971) versus 6:1 for the average carnivore, 14:1 for omnivores, and 20:1 for cattle (Gillespie 1987; Jurgens 1988; Ensminger et al. 1990)). Helm (1984) suggested that this short transit time may be attributed both to the seals' high metabolic rate and to the high water content of the prey tested. Markussen (1993) measured the transit time in harbor seals using carmine red and found that it varied between 2 and 6 hours, depended on the species of prey consumed and possibly, the activity rate of the seal. Krockenberger and Bryden (1994) measured the rate of passage of a marked meal in southern elephant seals (*Mirounga leonina*) using chromic-EDTA and ytterbium nitrate and found that the mean IDT was 9 h.

The mean IDT of 14 ± 4.8 h for the three Hawaiian monk seals studied was longer than IDTs reported for other pinnipeds at 2 - 6 h (Markussen 1993), 5 h (Helm 1984), and 9 h (Krockenberger and Bryden 1994). Generally, animals with longer intestinal tracts have slower rates of passage (Fish 1923); however, pinnipeds have very long intestines as compared to other carnivores, yet have rapid rates of digestion (Helm 1983, 1984). The digestive tract of the Hawaiian monk seal is currently being described (G. D. Goodman-Lowe, S. Atkinson, and J. R. Carpenter, in preparation) and preliminary data show the small intestine to body length ratio to be 7.2:1, which is comparable to that of the Mediterranean monk seal (*Monachus monachus*) at 5.7:1 (Schnapp et al. 1962). However, considering the high diversity of prey these seals eat (Goodman-Lowe, unpublished data), it is possible that their rate of passage may be longer as compared to temperate seals to facilitate digestion of such varied prey.

Age has been shown to affect rates of digestion, where young animals often digest food at a faster rate than adults (Warner 1981) and initial defecation time increases with age (Helm 1984). In previous pinniped studies, the seals tested were less than half the age of the Hawaiian monk seals used in the present study. Helm (1984) studied northern elephant seals, harbor seals, and California sea lions that ranged in age from a few weeks to 1.5 years, Markussen (1993) studied harbor seals that ranged from 3 months to 3 years of age, and Krockenberger and Bryden (1994) studied southern elephant seals that were approximately 4.5 years of age, whereas in the present study, the three monk seals examined were all adults whose ages range from 11 to 16 years. Therefore, the advanced ages of the Hawaiian monk seals may also have contributed to the slower IDT and rate of passage.

Activity level and fecal water content have also been shown to affect the rate of digestion in animals (Fish 1923; Helm 1984; Markussen 1993). In the present study, the IDT ranged from 9.5 to 19 h in Hawaiian monk seals restricted from aquatic activity (Cr_2O_3 marker), and from 10 to 21 h in monk seals with access to aquatic activity (corn kernel marker). Possibly due to inclement weather conditions, the seals with continual access to water remained in the pool from dusk until after dawn. However, since the IDTs in this study were similar to those from monk seals that were denied access to the pool, the IDTs did not appear to be affected by access to water or aquatic activity. Helm (1984) also found that seals fed indigestible particles such as charcoal had much longer IDTs, while Markussen (1993) found that indigestible hard parts of prey such as otoliths exhibited a longer transit time in harbor seals. Since un-masticated corn kernels are not well digested in carnivores, the IDTs tested using this method may have been prolonged by the nature of the marker.

Helm (1984) noted that the rapid IDTs found in his study may have been caused by their feeding regime where the seals were fed 3 small meals per day, since feeding animals continuously or ad libitum has been shown to increase the rate of passage in other animals (Seerly et al. 1962). Rate of passage is also increased through meal size, since a fuller gastrointestinal tract causes an increase in peristalsis. The seals used in the present study were fed one large meal per day rather than two to three meals per day as in the studies by Helm (1984), and Krockenberger and Bryden (1994), which could also partially explain the longer observed IDTs in the Hawaiian monk seals. Since wild Hawaiian monk seals are probably feeding opportunistically ad libitum with a consequent increase in gut content, their natural rate of passage is probably faster than that found in this study on captive monk seals.

Percent recovery of feces in this study was relatively low compared to that of many terrestrial animals. Since the feces of the seals in the present study were high in water content, they were rapidly dispersed over the concrete floor of the drained seal pool. In addition, some feces remained trapped between the hind flippers of the seals, which was not collected in an effort to keep interaction and stress to the seals at a minimum. Therefore, total recovery of feces was not possible.

Teleost prey of the seals are high in both protein and ash, therefore, a higher proportion of these substances are likely to be excreted. Consequently, in the Hawaiian monk seal, both protein and ash excretion were high and were also quite variable. The percent protein excreted may also have been increased by the presence and subsequent excretion of proteases in the digestive tract, which are needed to digest prey high in protein, such as teleosts. In addition, the various components of the seals' prey were most likely digested at different rates as shown by the variability in the ash excretion, which represents the mineral component (primarily calcium and phosphorous) of the prey. This may be explained by the fact that hard parts of prey, such as bones and otoliths, remain in the digestive tract longer than soft parts, such as organs and tissue (Treacy and Crawford 1981).

This study has provided the baseline information (i.e., IDTs and rates of passage of digesta) needed in order to further our understanding of the digestive physiology of Hawaiian monk seals. This can then be related to our understanding of the foraging ecology of these seals. Lack of prey abundance has been suggested as one of the causes of the recent decline in wild monk seals in the Northwestern Hawaiian Islands, particularly at French Frigate Shoals. Therefore, it is imperative that the nutritive value of the species preyed upon by Hawaiian monk seals is determined, and how they are assimilated is completely understood, to help prevent the further decline of this endangered species. The results of the present study have set the groundwork for these future studies.

Acknowledgments

We thank W. Gilmartin, K. Yates, J. Theodorou, M. Iwasa, and R. Peachy along with the staff and volunteers at the Waikiki Aquarium for their help and support in the logistics of this study, the many people who volunteered their time to help in the fecal collection process, as well as D. Boness and C. Lowe for reviewing this manuscript. This project was funded by Waikoloa Marine Life Fund, and, in part, by the Sea Grant College Program at the University of Hawaii (Institutional Grant No. NA36RG0507, publication UNHI-SEAGRANT-JC-95-33). The views expressed herein are those of the authors and do not reflect the views of NOAA or any of its subagencies.

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