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HAWAIIAN MONK SEALS (*MONACHUS SCHAUINSLANDI*) FORAGING IN DEEP-WATER CORAL BEDS

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ABSTRACT

Plans to harvest deep-water corals in the remote Northwestern Hawaiian Islands, close to populations of endangered Hawaiian monk seals (*Monachus schauinslandi*), have raised concerns about the seals' use of deep-water habitats. Movements and diving patterns of seals studied at French Frigate Shoals (FFS) Atoll indicated two areas where five males out of 33 instrumented seals dove deep enough (300–500 m) to encounter commercially sought deep-water corals. Submarine surveys conducted at each location found beds of gold (*Gerardia* sp.) and pink (*Corallium* sp.) precious coral suggesting an overlap between the foraging habitat of some seals and the target of the coral fishery. Areas adjacent to the coral beds that were visually censused using submersibles showed significantly fewer precious corals. Precious coral beds were not found on previous submarine surveys at other regions around FFS, supporting the notion that seals were selecting the areas with corals as forage habitat. Five male seals were fitted with back-mounted video cameras to document feeding among precious corals. None of the five seals dove deep enough to encounter precious corals (>300 m). However, three of the seals visited beds of black coral (*Cirrhipathes* sp.) at shallower depths (~80 m). One seal was observed revisiting the black coral beds on three successive nights to feed on fish hiding among the coral stems.

Key words: Hawaiian monk seal, *Monachus schauinslandi,* precious corals, deep-water corals, forage habitat, subphotic, CRITTERCAM, endangered species.

In recent years Hawaiian monk seals have been fitted with a range of telemetry instruments to characterize their movement patterns and diving behavior. In these studies there are often a small number of seals which dive considerably deeper than the rest of the sample. Some of this diving is likely to be an extension of search activity that focuses on shallower foraging grounds. However, some seals exhibit prolonged bouts of diving below the photic boundary, which raises the possibility that there is a separate forage ground at deeper depths. Such foraging behavior was observed during deployments of CRITTERCAMS (Marshall 1998) at French Frigate Shoals (FFS) between 1995 and 1997 (Parrish *et al.* 2000). Three of 24 instrumented seals repeatedly visited subphotic (>300 m) depths while the rest of the seals focused their foraging efforts shallower (<100 m). Unfortunately, the CRITTERCAMS were unlit, so no images were recorded while the deep-diving seals were below the photic boundary. At best, foraging could be inferred based only on recorded sounds of the seals interacting with the sea floor and on one video segment where a seal was recorded ascending into illuminated depths with a demersal fish in its maul. The type of habitat these seals were visiting was unknown.

The reemergence of the Hawaiian precious coral fishery in 1998 has prompted interest in understanding monk seals' use of deep-water resources. Colonies of precious corals are slow-growing filter feeders of the Class Anthozoa that are found at depths between 350 and 500 m (Grigg 1993). The coral trees grow on portions of hard bottom subject to high current flow producing patches or "beds" that represent a habitat type distinct from the surrounding sea floor. Although monk seals are not known to use deep-water corals (Nitta and Henderson 1993), the endangered status of this species requires an evaluation of potential interactions with this fishery. Monk seals in shallower depths (<100 m) have been documented to target the margins of reef ecotones and concentrate effort on bulk talus in their foraging (Parrish *et al.* 2000). If the seals continue to select specific forage habitats in deeper depths, then it is possible they have identified a particular substrate that improves their foraging success. Beds of deep-water corals could be one of those habitat types.

This paper reports dive profile and satellite telemetry data collected on Hawaiian monk seals to identify areas where seals have been diving to subphotic depths. A submersible was then used to survey the habitats of these areas, with particular attention paid to the occurrence of precious corals. Coral occurrence in adjacent areas was then assessed using a Remote Operated Vehicle (ROV) to conduct visual line transects. The occurrence of corals in these surveys was then compared to previous submarine surveys conducted in nearby regions. Finally, in an attempt to document seals feeding below the photic layer, seals were fitted with night vision CRITTERCAMS.

METHODS

Subphotic Diving

Abernathy (1999) at FFS Atoll, and Stewart (1998) at Pearl and Hermes Atoll, used satellite-linked time-depth recorders (SLTDR) to determine the locations of dive behavior. Five seals from FFS dived to subphotic depths. At Pearl and Hermes Atoll, only one seal dived to subphotic depths. Because Pearl and Hermes is considerably more remote and thus difficult to survey with a submarine, only the telemetry data from FFS were considered.

It is appropriate to briefly abstract the methods used by Abernathy (1999) to compile the telemetry data for the FFS region. Data were collected by attaching SLTDR to seals (n = 33) in both fall and spring seasons between 1992 and 1997. The sample included 10 adult females, 17 adult males, and 7 subadult males. Because one of the subadult males instrumented in 1993 exhibited open-ocean foraging, it was reinstrumented in 1997. The instruments were attached and retrieved when the seals hauled out on the various islets of the atoll. Seals were restrained and mildly sedated with an intravenous injection (0.13 mg/kg diazepam). Instruments were adhered to the pelage, just posterior to the scapulae, using a quick-setting epoxy. Throughout the 20–30 min procedure the seals remained conscious and were periodically cooled with seawater. Upon release, the SLTDR sent signals to satellite-based receivers operated by Service ARGOS. ARGOS positions were further assessed using a software called "Satel" (provided by Lloyd Lowry, Alaska Department of Fish and Game) which evaluates the swimming speed required for a seal to travel between the consecutive estimated positions and which indicates unrealistic positions, given the seals' actual swimming velocity. These suspect positions were then removed from the data set.

Dive profiles of the seals were collected in two ways. First, complete dive profiles were archived by the seal-mounted tag and were downloaded if the tag was recovered. Second, onboard processing recorded dive information into predetermined depth bins, and this histogram information was periodically transmitted.

Submarine Surveys

Satellite positions of seals that dove below the photic layer were pooled and plotted in relation to bathymetric contours. The sites of subphotic dives were then surveyed using the Hawaii Undersea Research Laboratory (HURL) submarine *Pisces V* and the ROV *RC-150*. The submarine was used to assess the site where the seals focused their activities. Surveys attempted to look across contours at each of the sites. The submarine's scanning sonar was monitored to identify topographic bottom features out to 80 m on either side of the submarine (160-m swath). The direction of the survey deviated to investigate these features as they were encountered. To survey more distant adjacent areas, linear transects using the ROV were conducted. The orientation and depth range of the transects differed between sites to accommodate the constraints imposed by bottom topography and current conditions. The data collected on an ROV transect provided a narrower "view" than data collected with the *Pisces V*, which has two cameras, sonar, and multiple observers at different view ports. Consequently, the site of the seals' subphotic diving was resurveyed with an ROV transect to provide comparable data to be used in an analysis of variance (ANOVA) of transects at adjacent areas by coral type. Coral presence, type, and density were recorded every five minutes on the transect. Specifically, the two primary commercial coral species, pink and gold, were noted. The presence and size of fish were also noted. These surveys were then considered in a wider context when compared with archived transcripts from previous submarine surveys conducted at other areas in the FFS region.[1]

CRITTERCAM Instrumentations

To obtain behavioral information on seals foraging at subphotic depths, CRITTERCAMS were deployed. Each camera was equipped with red light emitting diodes and image intensifiers to record in the low-light environment below the photic layer. The CRITTERCAMS were deployed on five male seals, including one with a previous history of subphotic foraging. The image intensification technology (night vision) limited recording to night hours only. Daytime sampling (*e.g.*, direct sunlight while the seal is surfacing) would have damaged the night vision component. The cameras were programed to record 3 min every 30 min on a 3-hr Hi8 video tape. With this sampling regime ≥3 nights of the seals' activities could be sampled. The CRITTERCAMS also continuously recorded the dive profiles of the seals. The video was reviewed for the habitat types visited and for foraging behavior.

RESULTS

Seal Movements

Most of the seals (22 of 33) shed their SLTDR tags at sea leaving only the depth histograms relayed by satellite to describe their dive activity. Depth histograms indicated that only one of these seals regularly dived at subphotic depths. Seal #5 had >25% of its total diving in the maximum depth bin (>100 m). Four other seals (three males, one female) logged only several dives in their deepest bin, (>100 m and >200 m) and therefore were not included in the analysis. Complete dive profiles were successfully recovered from 12 seals; seven of these (all male) made dives below the photic boundary. Two of the seals made only one or two dives to 300 m and were dropped from further analysis. The five remaining seals carried their instruments for an average 111 days (range 91–153 d) during which an average of 10% (range 1%–29%) of dives were at depths below the boundary layer (Fig. 1). Four seals (#1–#4) were adult males instrumented in spring 1996 and one (#5) in spring 1997. Seal #5 was the same male seal that had been instrumented in fall 1993. For seals #1–#4 both dive data and geographic position data were available. For seal #5 geographic positions were available from the 1993 instrumentation. The 1997 instrumentation produced only three reliable fixes, but archived a

[1] Hawaii Undersea Research Laboratory (HURL). 1984. Survey of French Frigate Shoals region with the submarine Makali'i—dive numbers 266 to 276. Hawaii Undersea Research Laboratory, University of Hawaii, 1000 Pope Road MSB 322, Honolulu, Hawaii 96822.

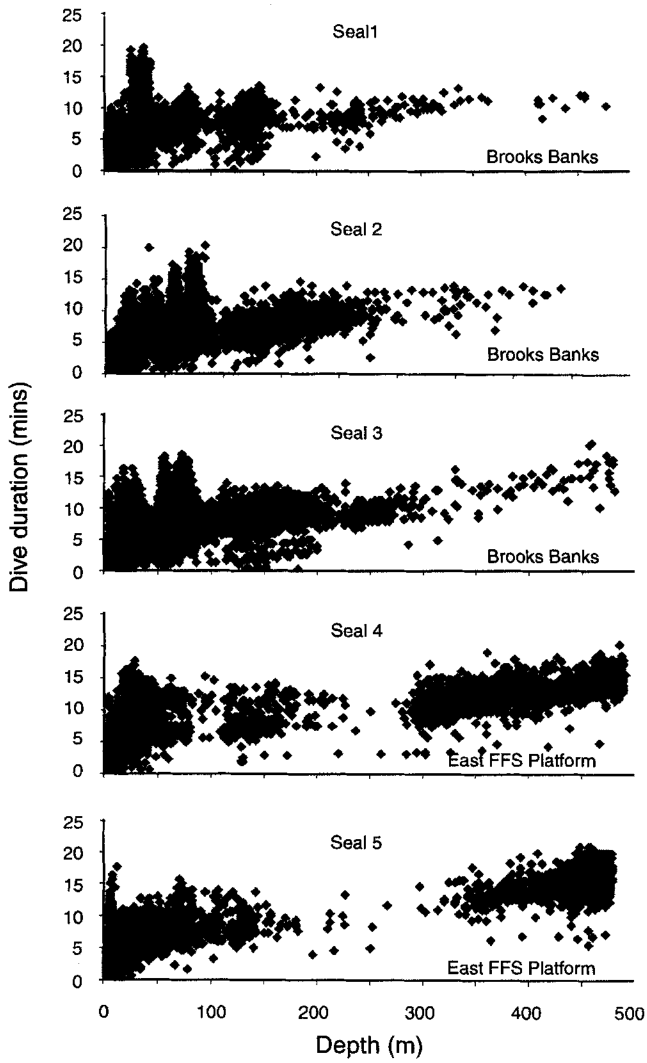

Figure 1. Dive depth and duration plots for five seals that visited subphotic depths. Regions of subphotic activity are listed in the lower right of each graph.

dive record that indicated ~50% of the total dive effort was spent between 300 and 500 m (the maximum limit of the depth recorder). In both instrumentations of seal #5 (1993 and 1997) the same geographic region was visited.

Pooling the locations of the dives for the five seals formed two clusters of oceanic activity (Fig. 2). One of the clusters contained seals #1, 2, and 3 which each made four or five trips to the summit and the deep slopes of Brooks Bank located to the west of the atoll. The second cluster contained seals #4 (seven trips) and #5 (nine trips) and centered on the distant east extension of the FFS platform where the shallowest depths of the submerged ridge ranged

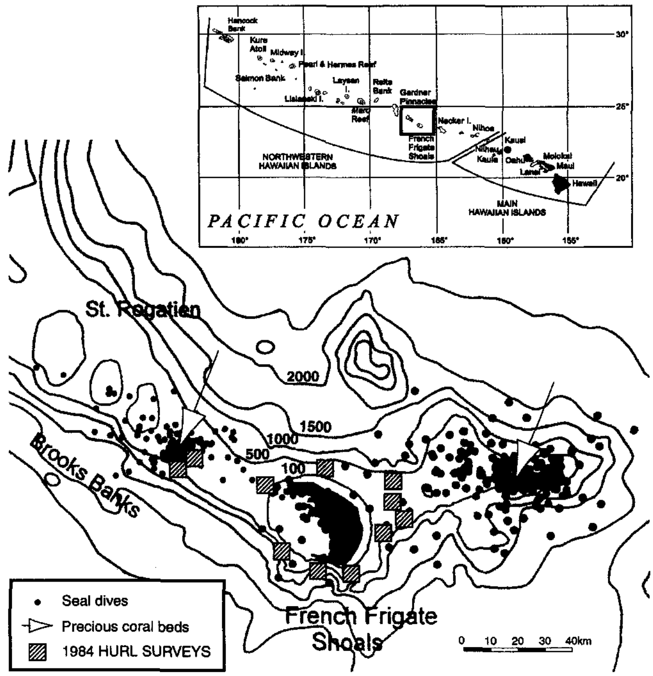

Figure 2. Map of French Frigate Shoals region with black dots used to indicate satellite telemetry positions of FFS seals that visited subphotic depths. Two arrows indicate where 1998 submarine surveys found precious coral beds at the center of seal foraging activities. Striped squares surrounding FFS indicate earlier submarine surveys conducted in 1984, which found no coral beds. Map of Hawaiian Archipelago is inset at top with FFS region highlighted.

between 333 and 400 m. The proportion of subphotic diving was much higher at the east FFS site than at the Brooks Bank site.

Habitat Surveys

The distance and depths covered on the submarine surveys and ROV transects are listed in Fig. 3. The surveys with the *Pisces V* began by descending at the center of each positional cluster formed by seal location data. In both locations the submarine landed on the bottom in the middle of a precious coral bed. For the remainder of this paper these two sites will be referred to as the Brooks Bed and the FFS Bed. Most prominent at the two beds were colonies of gold coral (*Gerardia* sp.) that formed large sea fans growing to more than a meter in height (Fig. 4A). In addition to gold coral, the Brooks Bed supported an abundance of pink corals (*Corallium* sp.) that grew to a maximum height of 30 cm (Fig. 4B).

The submarine survey of Brooks Bed found dense coral patches along the contour of the bank's west side. Some areas were mostly pink coral (hundreds of colonies) and other areas were primarily gold coral (>100 colonies). Deter-

Location	Depth (m)	Distance (km)
Brooks bed *Pisces V** survey	356-490	1.50
Bed ROV transect	429-573	0.50
Southwest ROV transect	154-500	1.68
Southeast ROV transect	144-427	1.60
East ROV transect	370-506	1.85
FFS bed *Pisces V** survey	352-374	1.10
Bed ROV transect	352-374	0.55
East ROV transect	362-465	3.00
South ROV transect	350-576	4.00
West ROV transect	370-384	1.80
North ROV transect	374-504	3.45

* Manned submarine

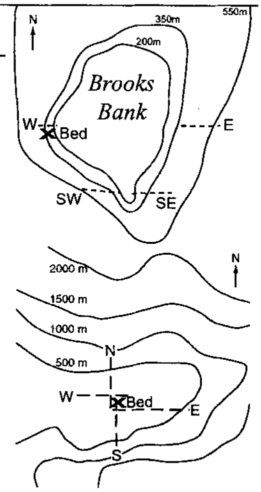

Figure 3. Depth range and distance covered by *Pisces V* and ROV surveys at Brooks Bank and FFS areas where seals made subphotic dives. Orientation of ROV transects relative to bathymetry and coral beds are characterized in adjacent diagrams.

mining the boundaries of the coral beds along the bank's contour was not possible. The pinks were found on tapered slopes at the north end of the survey, farther south the two coral types were intermixed, and at the southern extreme of the *Pisces V* survey, the bulk of gold corals was found encrusting tops of pinnacles and cliff faces. Significantly more pink coral was found at the Brooks Bed than adjacent areas on the east, southeast, and southwest areas of the bank (Table 1). The highest gold coral count was on the southwest transect.

In contrast, the bed on the east extension of the FFS platform appeared to be a solitary, discrete feature at which the bed's boundaries were more easily

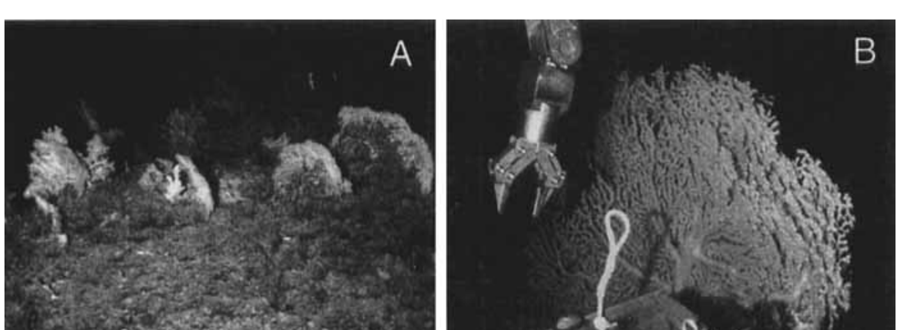

Figure 4. Photographs of primary targets of Hawaiian precious coral fishery. A-Colonies of pink corals (*Corallium* spp.) at near maximum height of 35 cm. B-A colony of gold coral (*Gerardia* sp.) at its maximum height of 90 cm. Manipulator of submarine is also present in the image.

Table 1. Results of analysis of variance (ANOVA) for coral type by ROV transect. In the *post hoc* section "bed" indicates sites of subphotic diving by seals. Transects are abbreviated by their direction (*e.g.*, E = east, SW = southwest) followed by the mean coral count in parenthesis.

Site (coral type)	*F* (df)	*P*	*Post hoc* differences between transects
Brooks (Pink)	19.79 (3, 63)	<0.001	Bed (29.7) > SW (1.4) SE (0.63) E (4.5)
(Gold)	2.51 (3, 63	0.06	SW (0.70) > Bed (0.14) SE (0) E (0)
FFS (Pink)	1.38 (4, 145)	NS	NA
(Gold)	11.50 (4, 145)	<0.001	Bed (2.3) > E (0.16) S (0) W (0) N (0)

defined. The submarine surveys documented >100 gold coral trees encrusting a series of basalt pinnacles 10 m high, covering an area approximately 400 m^2. Only a few small pink corals were observed in the *Pisces V* survey at the FFS bed. Pink coral was not found in any great abundance on any of the transects (Table 1). Significantly more gold was found at the bed than on any of the four ROV transects of adjacent areas. Only one patch of eight gold coral colonies was found, 3 km to the east of the FFS bed.

About 20 deep-water taxa including fish and cephalopods were commonly encountered on these surveys (Table 2). Many of the fish were slow moving and less armored than shallower reef species. Their mean sizes ranged from 10 to 70 cm in length and many of them were eels, or had an eel-like body

Table 2. List of deep-water fish frequently encountered by the submarine and ROV surveys. The general habitat, activity type, and mean size are listed for each fish.

Taxa	Habitat—activity type	Mean size (cm)
Squalus mitskurii	Bottom—searcher	40
Synaphobranchidae	Bottom—searcher	70
Chlorophthalmus sp.	Bottom—ambush predator	20
Myctophidae	Midwater—hoverer	10
Polymixiidae	Bottom—searcher	20
Laemonema sp.	Bottom—searcher	20
Physiculus sp.	Bottom—searcher	40
Chaunax sp.	Bottom—ambush predator	30
Beryx decadactylus	Bottom—searcher	20
Antogonia sp.	Bottom—hoverer	20
Zenopsis nubulosus	Midwater—hoverer	30
Grammicolepis sp.	Bottom—hoverer	20
Satyrichthys sp.	Bottom—searcher	10
Scorpaenidae	Bottom—ambush predator	10
Symphysanodon sp.	Bottom—hoverer	10
Decapterus sp.	Demersal—searcher	30
Chrionema sp.	Bottom—ambush predator	10
Hollardia goslinei	Bottom—hoverer	20
Chascanopsetta sp.	Bottom—ambush predator	20
Cephalopoda	Bottom—ambush predator	30

Table 3. Specifics from CRITTERCAMS deployed on five male seals including depth, sampled bottom time, fraction of time in black coral, and number of predation events for each seal.

Night vision CRITTERCAMS	Maximum depth (m)	Video of bottom (min)	Fraction of bottom time in black coral	Predation events [in black coral]
Seal 26	80	39	0.15	[4]
Seal 27	20	168	0	8
Seal 28	80	129	0.23	[26]
Seal 29	45	78	0	1
Seal 30	220	114	0.03	3

shape. These fish were present in the coral beds and in other habitat types. Some species were seen to swim or hover in the water column above the bottom and others appeared to be ambush predators resting on the bottom. A few taxa such as *Antigonia* sp. and *Hollardia goslinei* clearly associated with structural relief, including the deep-water corals.

Previous habitat surveys conducted by submarine in 1984 at other FFS regions found no precious coral beds. The surveys included six transects on the slopes of the atoll, two transects on the east side of Brook Banks, and three transects midway out on the east FFS extension (Fig. 2). Using this small number of regions that have been surveyed with submarines ($n = 13$), a categorical comparison of the coral presence-absence relative to the presence-absence of seal activity showed that the observed co-occurrence was significantly greater than expected (Fisher's Exact $P = 0.013$).

CRITTERCAM Instrumentation

Recorded dive profiles indicate that none of the five seals fitted with night-vision CRITTERCAMS visited subphotic depths, so there was no opportunity to record feeding in precious coral beds. Nevertheless, for the first time, seals were recorded to feed among filamentous, non-commercial species of black coral, *Cirrhipathes* sp. Dive records from the deployments indicate that the black coral occurred at moderate depths (~80 m, Table 3). Two of the seals never went deep enough to encounter the black coral. The remaining three seals visited the corals, but only two were seen to feed among them. Most of the feeding was by one seal which fed among the corals on three successive nights and spent its days resting in the lagoon, where it was visually monitored by the authors (Fig. 5). Roughly half of the total fish preyed upon ($n = 26$) were eels, averaging 30 cm in length (likely *Arisoma marginatum*). The remaining fish were smaller, hiding close to the bottom and required less chase time to capture, making identifications difficult. The few fish identified were the reef fish *Mypristis* sp.

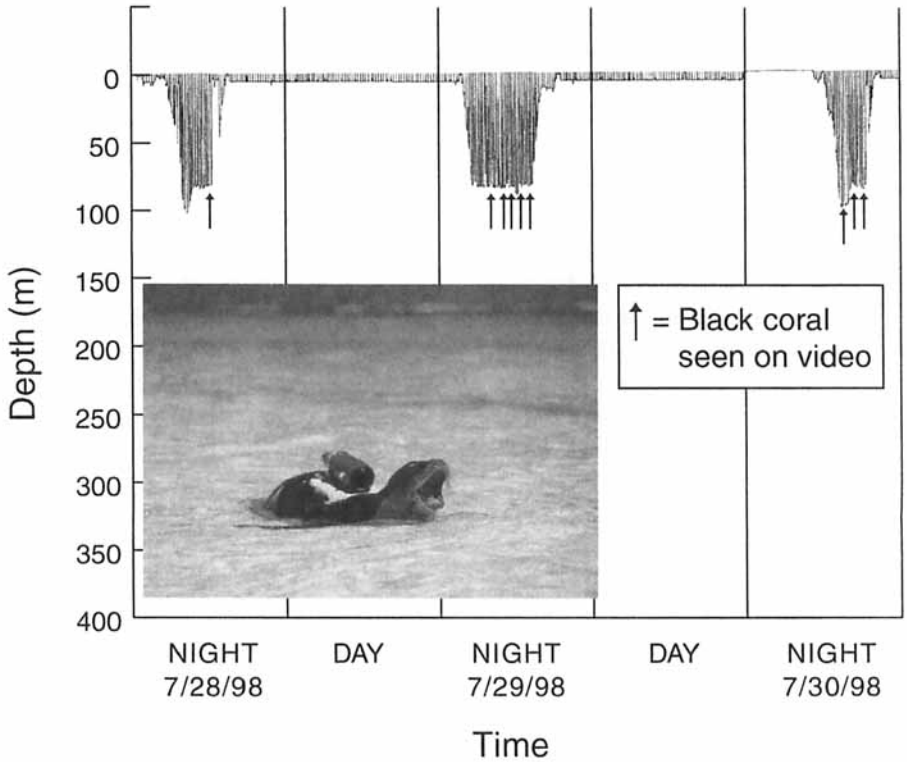

Figure 5. Dive profile of French Frigate Shoals monk seal fitted with night vision CRITTERCAM that indicates seal commuted between atoll and black coral bed on successive nights to feed. Arrows indicate where video sampling documented coral colonies. Daytime hours were spent resting in shallows of lagoon under visual surveillance of authors. Photo of monk seal fitted with CRITTERCAM inset at bottom. Photo by M. Craig.

DISCUSSION

Subphotic Diving

Only a small percentage of seals dived to subphotic depths in this study, and the data we have indicate these seals are likely to be male. Based on the fraction of deep-diving males in the sample (20%) and the population of males at FFS (NMFS, Honolulu Laboratory annual census data), we might expect around 34 males, or 10% of the total FFS seal population, to periodically visit subphotic depths. All available data on the seals' diet and feeding behavior indicate that monk seals feed on benthic and demersal prey. Goodman-Lowe (1998) characterized the monk seal diet by analyzing seal scats collected throughout the archipelago and found that all the prey taxa were demersal or benthic associated. Earlier studies using CRITTERCAMS on FFS seals, including the three subphotic divers discussed in the introduction to this paper, also showed only benthic foraging (Parrish *et al.* 2000).

Because seals rely on bottom-associated prey, their forage landscape is clearly defined. Seals depend on shallow (<100 m) coral reef ecosystems confined to the high peaks of the Hawaiian submarine ridge that are semi-isolated by the abyssal depths of the Pacific Basin. Seals resident to the ecosystem of one peak can extend their forage grounds by either traveling to another ecosystem on a neighboring peak or by foraging progressively deeper on the slopes of the submarine ridge. Presumably, monk seals will choose to feed at remote sites if it improves their feeding success over the forage grounds close to their FFS haul-out. Many seals at FFS have been documented to routinely visit and feed at neighboring banks as far as 400 km away (Abernathy 1999). Rather than travel long distances to summits of neighboring banks some seals may choose the alternative of staying close to the atoll and diving deep to forage in subphotic habitats. This strategy could be particularly appealing to male seals that want to maximize their time near the haul-outs of the atoll to pursue females.

Forage effort is not invested haphazardly at subphotic depths. Multiple trips were made by each seal to the coral beds during the period they were instrumented. Seals did not wander down the slope of the atoll into adjacent subphotic habitat. Instead they commuted between the atoll and forage areas. The video records of seals fitted with CRITTERCAMS at FFS (1995–1997) documented prolonged mid-water swims at ~20-m depth until they reached their forage grounds at neighboring banks or oceanic sites (Parrish *et al.* 2000). Once at these sites much of the diving behavior reflects the bottom topography. Seals at Brooks Bank made fewer deep dives than those at east FFS, probably because the summit of the Brooks Bank extends to within 80 m of the surface. Consequently, subphotic foraging by seals at Brooks Bank was an occasional deep extension of activity focused at shallower depths. However, out on the east FFS platform the shallowest depth observed was 333 m, so the seals had no alternative but to exclusively target habitat at subphotic depths. As a result, a higher percentage of the seals' diving effort in this location is subphotic.

It is unknown if a similar fraction of seals at other colonies in the archipelago use subphotic habitats. Our review of available telemetry studies produced little evidence of subphotic activity outside of FFS (Table 4). This could possibly relate to environmental conditions specific to FFS. Historically, the FFS seal colony has been considered the most stressed of those in the archipelago. The southerly location of FFS is in a region subject to significantly less exposure to seasonal encroachment of the higher primary productivity waters from the North Pacific (Polovina *et al.* 1995). Decadal changes in the frequency of exposure can reduce productivity, resulting in a decline of faunal communities at the atoll (Polovina *et al.* 1994) including reef fish (DeMartini *et al.* 1996), the primary food of seals. Because FFS seals may at times be food limited by the environmental dynamics of this distinct biogeographical region (Schmelzer 2000), their foraging may differ from colonies with a more stable prey base. Some seals in these circumstances may choose to dive deep rather than travel to neighboring reef systems to feed.

Table 4. Deep-water activities of monk seals with body-mounted depth of dive instruments in Hawaiian Archipelago. Listed for each study are location, sample size, duration of instrument deployment, number of seals that made deep-water (suphotic) dives, and deepest dive record.

Island location	Sample	Deployment	No. subphotic	Maximum depth	Reference
Lisianski Island	7 seals	~25 d	$n = 0$	180 m	Schlexer (1984)
Lisianski Island	6 seals	~13 d	$n = 0$	120 m	Delong *et al.* (1984)
Pearl and Hermes	21 seals	66–188 d	$n = 1$	552 m	Stewart (1998)
French Frigate Shoals	33 seals	~90 d	$n = 5$	350–500+ m	Abernathy (1999)
French Frigate Shoals	24 seals	2–9 d	$n = 3$	>300 m	Parrish *et al.* (2000)

Habitat Surveys

In general, this work and available habitat surveys from prior work, indicate that beds of deep-water corals represent a small portion of the total monk seal habitat. Deep-water coral habitats are known to be patchy, and the adequacy of visual line transects to represent the distribution of corals is debatable. The ROV surveys operate without the benefit of sonar and are close to the bottom, which likely introduces some bias in the ability to detect gold coral that tends to grow high on pinnacles and walls. However, few survey alternatives currently exist. The comparison of precious coral abundance (pink and gold) between the ROV transects indicated that the sites seals were visiting had significantly higher densities of precious coral than adjacent areas; thus, statistically justifying these sites as coral "beds." The size of these two beds also meets the informal fishery notion of a coral bed. In the fishery, the term coral bed generally refers to an area with coral densities high enough to invest in the costs associated with harvesting (*e.g.,* ships and submersibles). The 1984 HURL surveys conducted around FFS may have encountered sparse colonies of precious coral, but no precious coral beds were reported.

Seals' Use of Deep-water Corals

The seals' use of deep-water corals has yet to be firmly established. Coral beds are an uncommon habitat, yet the seals are clearly visiting sites where they occur. The fact that seals made multiple trips to subphotic depths at the only two sites where beds of precious corals have been found suggests there is some (at least incidental) use of the sites by seals. The spatial distribution in the satellite locations of monk seals and the wide depth distribution of the seals' subphotic diving effort indicate that their visits to coral beds are only a portion of a wider search activity. Seals also moved throughout adjacent deep slope habitat, with some dives extending beyond the 500-m maximum depth measurement capability of the instrument. Despite this, the positions of the seals' activities remain centered around the coral beds. This indicates that seals frequently revisited the area of the coral beds while foraging throughout the wider region. Whether this occurs because the coral beds improve the seals' foraging success remains unknown.

Few of the fish observed on these surveys have been documented as monk seal prey. Analysis of seal stomach contents (Kenyon and Rice 1959) and seal scats collected from the beach (Delong *et al.* 1984, Goodman-Lowe 1998) indicate most prey are shallow reef fish and invertebrates. The most comprehensive diet analysis (Goodman-Lowe 1998) did identify the deep-water fish *Polymixiidae* as a prey item, which was frequently seen on the submarine surveys both in and outside the coral beds. The scat data was collected over four years and at five Northwestern Hawaiian Banks (FFS, Laysan, Lisiansiki, Pearl and Hermes, and Kure). *Polymixiidae* was found every year, but only in the scats at FFS and surprisingly only in juveniles. Twenty-two percent of the fish prey fragments in the scat analysis were unidentified eels and it is probable some of these could be subphotic species. In addition to fish, a couple of deep-water cephalopods were evident in the scat data. However, the general lack of deep-water prey in the scat analysis likely reflects the small number of seals that forage at subphotic depths and the distance of subphotic feeding sites from the atoll. Given that food passes through monk seals between 9.5 and 19 h (Goodman-Lowe *et al.* 1997) it is possible the seals empty their bowels of deep-water prey during the 40–80-km transit back to the beaches of the atoll. One of the most frequent taxa found in the scat data was *Arisoma marginatum,* comprising >90 % of the fish otoliths (Goodman-Lowe 1998). This eel lives in moderate depths (80 m) on the slopes of the atoll and as a result is much closer (<4 km) to the seals' beach haul-out. The CRITTERCAM seals exhibited the ability to feed on these eels nightly and return to the beach during the day, a pattern of foraging which is likely to improve the eel's representation in the scat data.

The CRITTERCAM records of seals feeding on eels among black corals provide some basis to infer that deep-water corals provide forage habitat for seals. Although feeding among black corals does not prove that seals are feeding among precious corals, it does establish that the seals forage among deep-water coral patches. Patches of non-commercial coral may be as important as patches of precious corals. The range of black coral species spans depths from 30 to 500 m (Grigg and Opresko, 1977) affording seals an unknown number of patches at subphotic and shallower depths. Seals may preferentially search productive areas of steep topography and increased water flow at which deep-water corals happen to grow best and fish commonly occur. However, fish were seen in all habitat types and not just in the area of the coral beds. A separate effort is necessary to address the occurrence of deep-water fish assemblages in relation to benthic habitats including deep-water corals. In particular, replicate fish surveys need to be conducted in coral beds and a range of other deep-water habitats to evaluate whether coral beds aggregate prey and improve the seals' chances of feeding success. Fish could move from adjacent barren habitats to the improved shelter and prey sources afforded by the coral beds, increasing the seals' likelihood of finding fish at the bed. Seals may frequently interrupt their search of the wider region to raid the coral beds and feed on any fish that have recently moved in. Exploiting the coral beds in this manner could improve the seals' overall foraging success. Additional work is needed to determine the nature of the seals' subphotic forage base and what ecological role, if any, deep-water corals contribute to it. Results from such studies will be an important consideration in the future management of the Hawaiian precious coral fishery.

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