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# Monitoring the diurnal and seasonal foraging of Hawaiian monk seals in mesophotic rubble habitat using seafloor event loggers called 'electric rocks'

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ABSTRACT: Video from cameras fitted to Hawaiian monk seals showed that seals visited patches of loose mesophotic seafloor rock to flip them and obtain the prey hiding underneath. Diver surveys of rock patches documented 38 species of fish and invertebrates and found 38% of the larger diameter rocks (10–100 cm) flipped with the encrusted live coral and algae side left face down. We developed a set of 'electric rocks' (artificial rocks fitted with event loggers) to record the date and time of any movement. We deployed the rocks in multiple clusters on the terraced slope of the seal colony atoll (French Frigate Shoals) close to the beach haulout and at 2 sites further away on the summits of neighboring banks. The goal was to expand temporal monitoring (diurnally and seasonally) of the seal's use of mesophotic rubble patches without requiring further instrumentation of monk seals. The data from the electric rocks showed patterns consistent with the behavior seen from the seal-mounted video, including rapid rock-to-rock searching and more movements closer to seal haulouts. The electric rocks detected more rock tips on the atoll terrace than on the banks, with higher counts seen during the day at the bank summits. Seasonally, both the terrace and bank detected more movements in summer and fall months consistent with the monk seal's reproductive pupping and molting season than during the rest of the year, suggesting some seasonal change in the foraging habitat of monk seals.

KEY WORDS: Marine mammals · Mesophotic foraging · Monitoring · Predator–prey interactions · Rock moving

## 1. INTRODUCTION

Hawaiian monk seals *Neomonachus schauinslandi* are foraging generalists that feed on a range of benthic-associated fish and invertebrates (Goodman-Lowe 1998, Longnecker et al. 2006, Longnecker 2010, Cahoon 2011, Iverson et al. 2011, Cahoon et al. 2013). Monk seals are an endangered species, and historical declines in population numbers at the Hawaiian atoll of Lalo (listed as French Frigate Shoals on navigation charts; Fig. 1A) prompted a wide range of foraging studies. Emaciation in young seals was the primary threat to the survivorship of the colony and drove the need to understand monk seal feeding and their foraging landscape (NMFS 2007). Prior research using seal-mounted video cameras (42 monk seals instrumented; Fig. 1B) collected 45 h of video that identified a wide range of foraging habitats used by the seals (Parrish et al. 2000, 2008). Roughly 7% of the foraging video collected showed 9 seals visiting rubble

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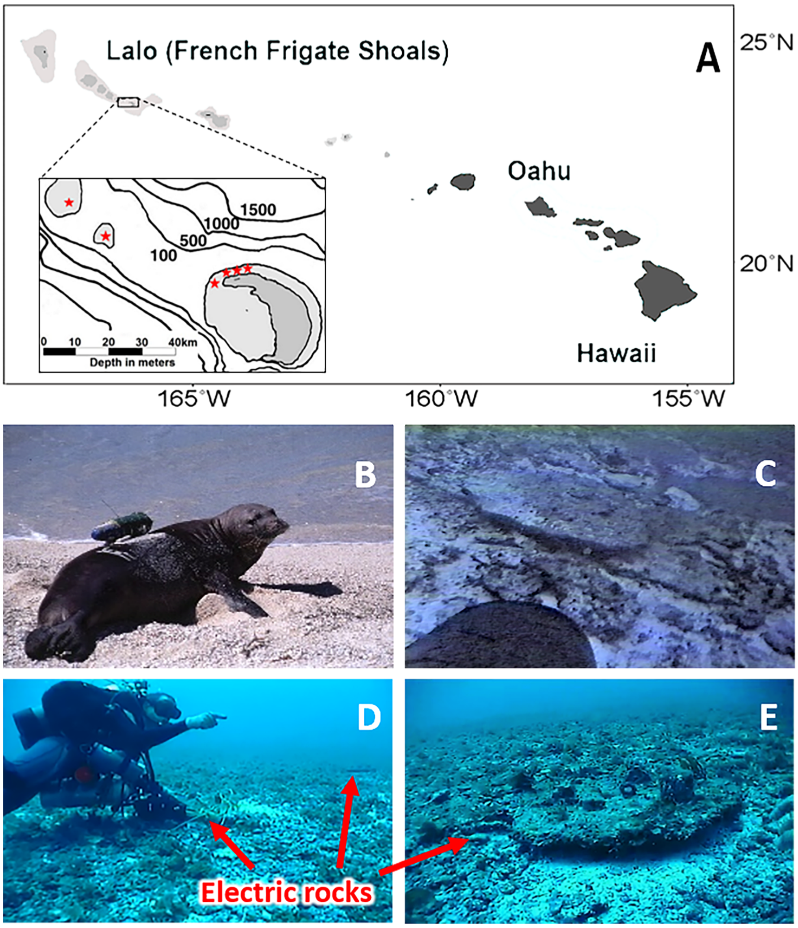

Fig. 1. (A) Hawaiian Archipelago with an inset of the French Frigate Shoals region. Clusters of electric rocks (red stars) placed outside the atoll barrier reef and on the summits of the 2 neighboring banks. (B) Photo of monk seal instrumented with a CRITTERCAM. (C) CRITTERCAM video capture showing the seal's head in the lower left corner and a natural seafloor rock it is about to search. (D) Diver in a cluster of electric rocks deployed within sight of each other. (E) Close-up of electric rock

patches at 30–150 m, a depth range commonly referred to as the mesophotic (Hinderstein et al. 2010, Baker et al. 2016, Pyle et al. 2016). The seals with the highest rate of prey capture included those that visited rubble patches and moved large individual loose rocks to flush out and capture prey sheltering around and underneath (Fig. 1C). Similar relief features on otherwise uniform bottom tracts are known to attract the visitation of seals for both patches of natural habitat (Parrish et al. 2002) and anthropogenic structures installed on the seafloor (Russell et al. 2014, Arnould et al. 2015). We know little about marine mammals moving seafloor features to search for prey. The best example is the sea otter *Enhydra lutris*. It is known to move rocks 50–100 cm in size to obtain prey items (Vanblaricom 1988, Kvitek et al. 1989) and uses stones to open bivalves (Hall & Schaller 1964, Fujii et al. 2015). Rock-moving behavior is largely undocumented for other marine mammals. Even with the increased use of animal-borne imaging devices on marine mammals worldwide (Marshall et al. 2008), this behavior remains rarely investigated.

Monk seals effectively search isolated accumulations of loose rocks at mesophotic depths, where they flush and capture prey with greater success than in the more structurally complex shallow reefs. When flushed from cover, a prey item sheltering around an isolated loose rock has no place to flee and hide except back to the same rock, which the seal can quickly move and search again if needed. Unfortunately, the short duration of seal-mounted video camera deployments (36–72 h) limits our temporal view, with no insight into diurnal and seasonal patterns. This paper reports on an attempt to expand the temporal view of the monk seals' use of this habitat by recording the movement of artificial seafloor rocks large enough that few animals other than a monk seal could move them.

Our goal was to understand the seal's use of the rock habitat to feed on the associated prey community and see if there was a way to monitor the seals' use of this habitat over time. In the short term, we wanted to determine if the behavior seen in summer seal-mounted camera studies is representative of the seal's activities for the rest of the year. In the long term, it would monitor part of the seals foraging landscape over successive years. The steep nature of the Hawaiian ridge means monk seals use a broad range of habitats that vary among and within depths extending down to 500 m such that they can change what they eat without long transits. The seal's searching of the mesophotic rubble field functions as a gateway habitat seals pass through when moving between their prey communities of the shallow coral reef and the deep slope. This situation presents a rare opportunity for us to monitor the monk seal's use of a specific foraging habitat through time.

The 3 steps in our study were: first, review the available seal-mounted CRITTERCAM video to document the seals' behavior and identify the rock patches' location; second, conduct surveys of the fish assemblages in the rock patches and inspect the larger individual rocks for hiding prey and any evidence of having been recently searched; and third, develop a set of similarly shaped artificial rocks with battery-powered event loggers. We placed these 'electric rocks' within the rubble patches to record the date and time when they were moved. We then looked for consistency in the data patterns of electric rocks with the seal-mounted cameras and any diurnal and seasonal patterns.

## 2. MATERIALS AND METHODS

### 2.1. Monk seals feeding in mesophotic rock patches

The seal-mounted video came from prior foraging studies on French Frigate Shoals (FFS) monk seals using animal-borne imaging systems (Marshall 1998), including the National Geographic Missions Program CRITTERCAM and Wild Insight Venus UTPR (underwater timed picture recorder). Cameras were attached to 42 seals from 1995–2002, including adult males and male and female juveniles (Parrish et al. 2000, 2002, 2005). The permits did not allow attachments to adult females to avoid potential pregnancy impacts. Segments of up to 90 s of video were recorded every 15–30 min during the seal's time at sea until the tape was full. Excluding time spent resting in underwater caves and interacting with other seals, the cameras recorded 45 h of travel, including their foraging activities. We looked for the segments where seals visited and searched patches of loose sea floor rocks to capture hiding prey. Direct surface observations of seals with cameras at sites with loose rocks, habitat depth, very high frequency (VHF) tracking, and visual confirmation of landmarks confirmed the location of the rock patches visited by the foraging monk seals. Loose rock accumulates in areas of level bottom shaped by the prehistoric stands of sea level (Jones 1993, Fletcher et al. 2008). The patch closest to the beach haulouts at the atoll (<6 km) was a rubble belt that accumulated at the base of the barrier reef slope on the north terrace. Loose rock also accumulated on nearby bank summits where sand drains downslope, exposing bulk talus fragments. The closest bank is Southeast Brooks Bank (44 km), and the next closest is Middle Brooks Bank (64 km). We tallied video segments where monk seals searched loose rocks and, for each segment, calculated the number of rock searches per minute and identified the maximum handling time for individual rocks. Also noted were the maximum number of large-bodied jacks (Dale et al. 2011a) and sharks (Dale et al. 2011b) competing for prey items flushed from cover by the seals (Parrish et al. 2008). This information guided our strategy for subsequent dive surveys and the design of our electric rock data loggers.

### 2.2. Diver surveys of mesophotic rock patches

In August 1998 and 1999, divers surveyed the mesophotic patch of loose rock on the atoll terrace (Fig. 1) that ranged between 1.75 and 5.9 km from the beach islets at the atoll where the seals haul out to rest. In 1998, divers tallied fish and conspicuous invertebrates during 20 min swims at 8, 75 m long by 2 m wide, belt surveys (150 m$^2$) conducted at 2 depths (50 and 60 m) looking for greater prey densities around loose rocks. These standardized fish counts were a deep extension of wider reef fish community surveys at the atoll looking at the monk seal prey base (DeMartini et al. 2002). The prey counts were $\log_{10}(x + 1)$ transformed in a parametric 2-way ANOVA to look at the nested depth effect within the site. Because there were more rocks at 50 m, that contour was re-surveyed in 1999 with divers looking exclusively at the most prominent individual rocks, noting the size, growth of live coral and algae, and the associated fish and invertebrates.

### 2.3. Development of electric rocks

The electric rocks were similar to natural rocks, being carbonate (Quickrete mortar mix), flat, circular, and 50–60 cm in diameter (Fig. 1E). They weighed ~20.5 kg. They had 3 symmetrically arranged high points on each side of the rock to serve as tripod legs to stabilize the electric rock between tips. One of the legs was a PVC cylinder that held the event data logger to capture the date and time when moved (Onset Hobo). Our data logger predates accelerometers, so all types of movement were logged as an event without further description. The movement could be as little as a rock shudder from passing swell energy or multiple tumbles of the rock associated with a monk seal searching it for prey. Because the count of the events varied widely with different types of movement, each initial movement was followed by a 15 s pause before the data logger would record the next event. The 15 s pause was adopted because the seal-mounted video recorded seals spending a max of 10 s moving and searching the rocks before moving on. Data collected from bench tests and month-long summer field trials of electric rocks in the main Hawaiian Islands (well away from seal colonies) showed no movements other than those made by the authors to confirm function. Also recorded was the hourly temperature in °C. The electric rocks were deployed haphazardly in clusters of 3 dropped from the surface with an attempted spread of no more than 5 m so they would be in sight of each other on the bottom (Fig. 1D,E) such that passing seals would see more than just 1 electric rock and would search the cluster. In 2001, during the fall months, we dropped 3 clusters of electric rocks along the rubble contour on the terrace at the base of the atoll's northern barrier slope. In 2002 we made year-long deployments of 2 clusters of rocks on the atoll terrace and a cluster on each summit of the closest neighboring banks (Southeast Brooks Bank and Middle Brooks Bank). In 2003 we monitored a single cluster (Middle Brooks Bank) because logistical constraints limited diving operations to conventional depths. Divers who searched for and recovered the data loggers noted the condition of the electric rocks (flipped status, fouling, and any associated fish). With the loss of some rocks, our sample size was 20 electric rocks, with the cluster number at each site varying between 2 and 3 rocks.

When wave periods (e.g. North Pacific storms) are large enough, they generate bottom surges to varying degrees attenuated by depth (Bekkby et al. 2008) that can move the loose rocks resting on the bottom. We had to exclude this source of movement from the electric rock data. There is little information about wave effects on the movement of large rocks (van Rijn 2019) and none for rocks at mesophotic depths, so for wave influences, we compared the patterns of detected movements to wave buoy data. Comparing the movement data from the electric rocks to the mean daily wave data from the Coastal Data Information Program buoy (CDIP; http://cdip.ucsd.edu, accessed May 5, 2020) on the north shore of Oahu (Waimea) identified the threshold when the bottom surge moved the electric rocks. We attributed movements to wave influence and excluded it from further analysis when the mean wave period exceeded the identified threshold or there were abrupt spikes in counts. Text S1 and Figs. S1 & S2 detailing the days excluded due to wave events are available in the Supplement at www.int-res.com/articles/suppl/n051p293_supp.pdf.

We did the analyses on the remaining 'tips' to look for confirmation that the electric rock data is consistent with patterns seen in the seal-mounted video and then looked at the data for diurnal and seasonal patterns (the primary goal for the electric rocks). Analyses of the tip data relied on nonparametric statistical tests: Spearman rank order correlation (SPROC) for the effect of distance from haulout and duration of monitoring, and Kruskal-Wallis (KW) tests for the comparison of means among clusters for site effects. The Mann-Whitney *U*-test was used to look for differences in diurnal patterns between bank and terrace sites and for the one cluster with an inter-annual comparison. All tests were applied using IBM SPSS v24 with significance defined when tests returned an alpha level of $p < 0.05$ (Siegel & Castellan 1988).

## 3. RESULTS

### 3.1. Monk seal use of rock patches

Roughly a quarter of the 42 seals (33 adult males, 6 juvenile males, 3 juvenile females) instrumented (n = 9 males, 8 adults and 1 juvenile) provided 91 video segments showing seals feeding among loose rock habitats for 19 % of the total video recorded (Table 1). All seals in rock habitat moved and searched loose rocks for prey. The rocks were flat carbonate slabs ~40–80 cm in diameter (Fig. 1E) that the seals would spend no more than 10 s handling and consuming prey before departing to search elsewhere. Some rocks were more conspicuous than others, as if flipped and left with their underside without algal or coral growth facing up. The seals could flip the rocks except for the one juvenile that moved a large rock by sliding it sideways on the bottom but appeared unable to lift and access any prey hiding underneath. The rate at which the seals searched the rocks ranged from a low level of single opportunistic searches (4 seals) to rapid, successive rock-to-rock visits that exceeded a rate of 3 searches $\text{min}^{-1}$ (3 seals). The seals engaged in a high search rate visited both the terrace and the banks. Also seen at the terrace and the banks, but more commonly at the banks, were jacks (*Caranx ignobilis*, *Seriola dumerili*, *Caranx melampygus*), sharks (*Triaenodon obesus*, *Carcharhinus* sp.), and adult reef snappers (*Aprion virescens*). These large-bodied fish species followed the foraging monk seals to compete for the prey items the seals flushed from hiding. Kleptoparasitism occurred with the largest jacks and sharks.

### 3.2. Diver observations of rubble patches

The 1998 diver surveys at the atoll terrace documented the fish seen in the rubble habitat that accumulated between the base of the barrier slope and the sandy expanse covering the level area of the north terrace. The only sources of relief were the large rock fragments that had slid down slope after being dislodged from the shallower barrier reef. The number of large loose rocks appeared to diminish with greater depth. Divers counted about twice the number of fish species (mean 28.2 ± 4.6 per transect) at 50 m, where there were more rocks, than the surveys at 60 m (mean 14.8 ± 2.1). The 2-way ANOVA looking at total fish number (response variable) seen on the transects relative to depth (explanatory variable) was marginally significant (depth $F = 2.74_4$, $p < 0.046$, site $F = 2.84_3$, $p < 0.054$) showing greater fish among the rocks along the 50 m contour. The 1999 diver surveys to the 50 m contour focused on the largest rocks. They inspected 83 rocks that ranged in size from 10 to 100 cm (mean ± SD; 43 ± 19 cm) in diameter, with roughly a third on each transect (18–60%) appearing flipped with the algal and coral-encrusted side left facing down (Fig. 2A). One rock encountered was 60 cm in diameter and was standing vertically on its end such that when the diver tapped it, it fell over. Thirty-eight species of fish and invertebrates (Table 2) used the rocks as shelter. Divers documented a mean of 5.5 fish (SD 8.78) per rock with no correlation (Pearson r = 0.028, p = 0.42) to the diameter of the rock (Fig. 2B). As expected, looking under the rocks, we found more fish species and some crustaceans (*Stenopus hispidus, Dardanus gemmatus*), exceeding the number of taxa seen on the belt transects by 40%. Apogonidae and *Sargocentron* sp. were the most numerous cryptic fish species. The density of fish around the individual loose rocks averaged 17.2 (SD 21.9) times that of the density seen on the belt transects. We have no similar fish surveys at the bank summits; however, based on video from the seal-mounted cameras and anecdotal observations from divers who recovered the electric rocks, there appeared to be

Table 1. Location of 3 areas with loose rock visited by monk seals with seal-mounted video cameras. Left side of table shows the individual seal ID and the total time spent foraging in all habitats; right side shows total time, search rate, and number of competitors seen on the video segments where the seals were searching rocks

| Location | Seal ID | Total min | Video of rocks being searched Total min | Search rate (mean $\text{min}^{-1}$) | Comp./video seg. Mean (SD) |
|---|---|---|---|---|---|
| FFS (Lalo) Terrace | cam 4 | 74 | 14.8 | 1.8 | 1.8 (1.09) |
| | cam 22 | 110.9 | 4.2 | 1.8 | 0 |
| | cam 25 | 11.8 | 1.5 | 1.8 | 0 |
| | cam 29 | 88.4 | 1.5 | 2.7 | 0 |
| | cam 36 | 56 | 1.5 | 2.7 | 0 |
| | cam 37 | 49.1 | 1.5 | 0.6 | 0 |
| | cam 41 | 74.3 | 37.5 | 3.4 | 1.46 (0.87) |
| SE Brooks Bank | cam 6 | 97.8 | 36 | 3.6 | 10.5 (7.38) |
| Middle Brooks Bank | cam 13 | 100 | 26 | 3.6 | 12.7 (11.76) |

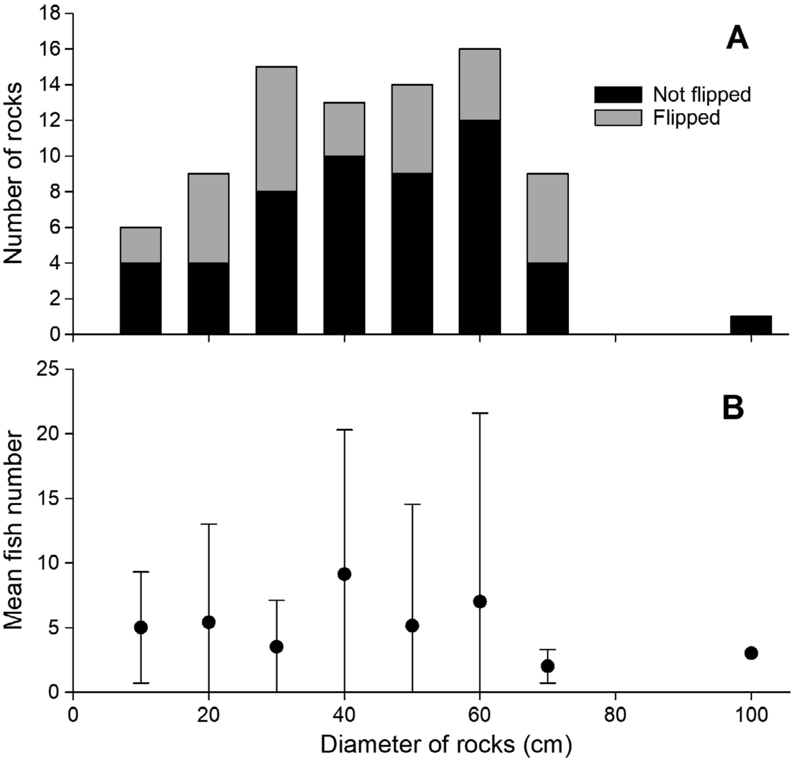

Fig. 2. (A) Number of rocks by diameter seen by divers. Light portion of the bar indicates evidence of being flipped (e.g. live coral or algae found face down on the rock's underside). (B) Mean (SD) of the fish number seen by divers sheltering around the different-sized rocks

more reef fish than at the terrace sites. The summit of Southeast Brooks was hard bottom with a mixture of sizeable loose rock fragments; Middle Brooks had isolated loose rock fragments within algal meadows (mostly *Microdictyon* sp.). These habitats contrast the terrace where seals sought prey in the sand field or among the loose rocks on the adjacent rubble belt.

### 3.3. Seal searching of electric rocks

Having excluded electric rock movements due to wave events (see Figs. S1 & S2), the remaining tip data showed patterns consistent with the behavior seen in the seal-mounted videos. Multiple tips recorded on the same day within the rock clusters comprised 27% of the data averaging 3.6 (SD 4.1) tips d$^{-1}$. We are curious to know if this is from one or many seals. The seal-mounted videos showed 3 monk seals with the highest search rate (Table 1) targeting the rock habitat. Quick rock-to-rock searching means the interval time recorded between tips in a cluster of electric rocks should be very short. Indeed, we see this peak in our shortest interval bin (<2 min) for the clusters on both the terrace and the banks. As the recorded interval times between tips within a cluster get longer, the peak from seals targeting rocks changes to a low level at intervals greater than 10 min, which is more consistent with the seals opportunistically encountering and searching rocks on their way to somewhere else (Text S2, Fig. S3). Looking across all the deployed rocks on the terrace of the atoll, we saw an effect of distance (explanatory variable) from the seal's beach haulout on the mean tips d$^{-1}$ (response variable) (SPROC $r_s = -0.650$, $p = 0.003$). However, this did not persist for those placed on the more distant bank summits ($r_s = -0.542$, $p = 0.083$) (Fig. S4).

For the 3 clusters placed on the terrace close to the seal's beach haul out during the fall of 2001, the mean number of tips d$^{-1}$ did not significantly differ (KW $\chi^2 = 0.631$ df = 2, $p = 0.730$). In contrast, the 4 clusters deployed year-round in 2002 spread over greater distances from the terrace to the banks showed significantly more tips ($\chi^2 = 16.4$ df = 3, $p = 0.001$) at the terrace close to the seal haulout. Of the clusters on the 2 banks, the one closer to the haulout (Southeast Brooks) had more searchers. The Middle Brooks Bank rock cluster was our only inter-annual comparison, and it showed more visitation in the second year (2003), but the difference was not significant (Mann-Whitney $U = 152.5$, $n_1 = 9$, $n_2 = 37$ $p = 0.69$).

Table 2. Diver inspection (1999) of 83 natural rocks showing the total number, mean, and SD of taxa hiding in the loose rock along the 50 m contour of the terrace

| Fish and large invertebrate taxa | Total | Mean | SD |
|---|---|---|---|
| *Anthias* sp. | 47 | 0.562 | 3.633 |
| Apogonidae | 37 | 0.445 | 1.540 |
| *Sargocentron* sp. | 32 | 0.385 | 1.488 |
| *Dascyllus albisella* | 26 | 0.313 | 1.178 |
| *Stenopus hispidus* | 23 | 0.277 | 0.590 |
| *Dardanus gemmatus* | 11 | 0.132 | 0.406 |
| *Coris ballieui* | 11 | 0.132 | 0.745 |
| *Coris venusta* | 11 | 0.132 | 1.101 |
| *Heniochus diphreutes* | 6 | 0.072 | 0.658 |
| *Chaetodon fremblii* | 6 | 0.072 | 0.260 |
| *Chromis verater* | 5 | 0.060 | 0.393 |
| *Chaetodon miliaris* | 4 | 0.048 | 0.266 |
| *Canthigaster jactator* | 4 | 0.048 | 0.266 |
| *Oxycheilinus bimaculatus* | 4 | 0.048 | 0.215 |
| *Genicanthus personatus* | 3 | 0.036 | 0.187 |
| *Canthigaster coronata* | 3 | 0.036 | 0.187 |
| *Centropyge potteri* | 2 | 0.024 | 0.154 |
| *Parupeneus multifasciatus* | 2 | 0.024 | 0.219 |
| *Chaetodon kleinii* | 2 | 0.024 | 0.154 |
| *Anampses chrysocephalus* | 2 | 0.024 | 0.219 |
| Scorpaenidae | 2 | 0.024 | 0.154 |
| *Chaetodon multicinctus* | 1 | 0.012 | 0.109 |
| *Bodianus bilunulatus* | 1 | 0.012 | 0.109 |
| *Acanthurus olivaceus* | 1 | 0.012 | 0.109 |
| *Sufflamen bursa* | 1 | 0.012 | 0.109 |
| *Labroides phthirophagus* | 1 | 0.012 | 0.109 |
| *Oxycirrhites typus* | 1 | 0.012 | 0.109 |
| *Acanthurus* sp. | 1 | 0.012 | 0.109 |
| *Parapecis* sp. | 1 | 0.012 | 0.109 |
| *Plectroglyphidodon johnstonianus* | 1 | 0.012 | 0.109 |
| *Pseudojuloides cerasinus* | 1 | 0.012 | 0.109 |
| *Gymnothorax* sp. | 1 | 0.012 | 0.109 |
| *Gymnothorax meleagris* | 1 | 0.012 | 0.109 |
| *Rhinecanthus rectangulus* | 1 | 0.012 | 0.109 |
| *Conger marginatus* | 1 | 0.012 | 0.109 |
| *Enoplometopus occidntalis* | 1 | 0.012 | 0.109 |
| *Macropharyngodon geoffroy* | 1 | 0.012 | 0.109 |
| *Pseudocheilinus octotaenia* | 1 | 0.012 | 0.109 |

Given the consistency of the electric rock tip data with observations from the seal-mounted video, we felt there was merit in looking at the tip data to infer diurnal and seasonal patterns. The mean number of tips (response variable) distributed over the 24 h cycle showed that the terrace and bank sites (explanatory variable) did differ (Mann-Whitney $U = 98$, $p < 0.001$). The terrace averaged more visitation than the banks, with searches roughly divided equally day and night (Fig. 3). There was a mid-day peak in the number of tips in both areas. Plotting the data binned by month showed that the mean tips d$^{-1}$ was roughly equal between the terrace and the banks, with both showing higher levels in the late summer and fall months (Fig. 4). The seasonal skew in the monthly mean tips d$^{-1}$ (response variable) did not positively correlate ($r_s$ = 0.312, p = 0.162) with more monthly days of monitoring effort (explanatory variable). From December to January, the monitoring window rapidly declines to its lowest level associated with winter storm waves extending into early spring. In April, the monitoring window expands, including the entire month, but the number of tips detected remains low until an increase in July. The seasonal pattern in electric rock tips does not appear to be a function of the monitoring duration and may relate to monk seals' seasonal behavior.

## 4. DISCUSSION

### 4.1. Monk seal foraging in loose rock habitat

Our archive of video from seal-mounted camera deployments showed that rock searching was a strategy employed by roughly a quarter of the instrumented seals. With no instruments on adult females, we do not know how important the loose rock habitat is to them, but likely, female seals of a similar size as males will probably also search loose rocks for prey items. Comparing dive profiles of the same seals, both with and without mounted-video cameras, suggests that the behavior we see on video is represen-

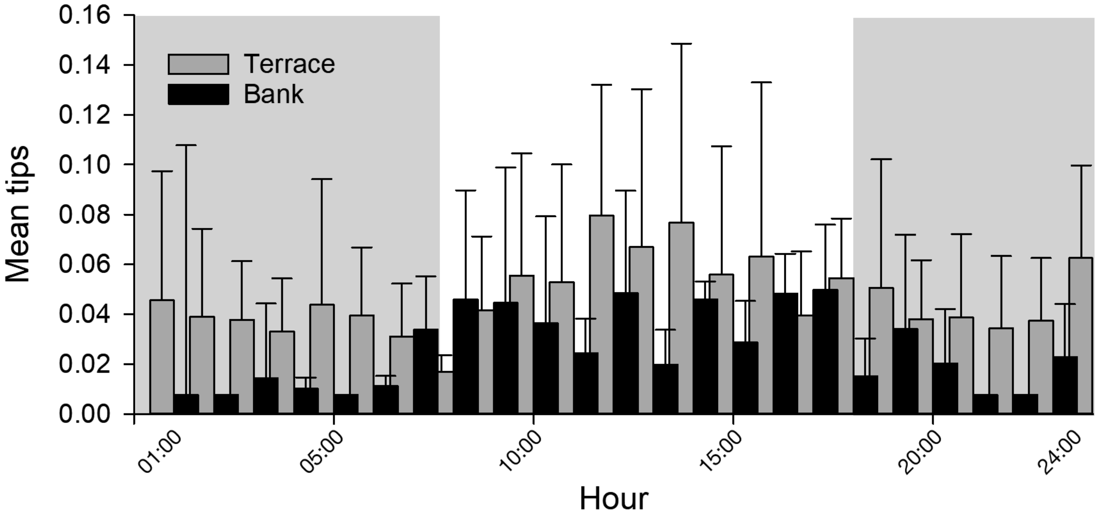

Fig. 3. Distribution of the mean (+SD) hourly rate of electric rock tips over the diurnal cycle

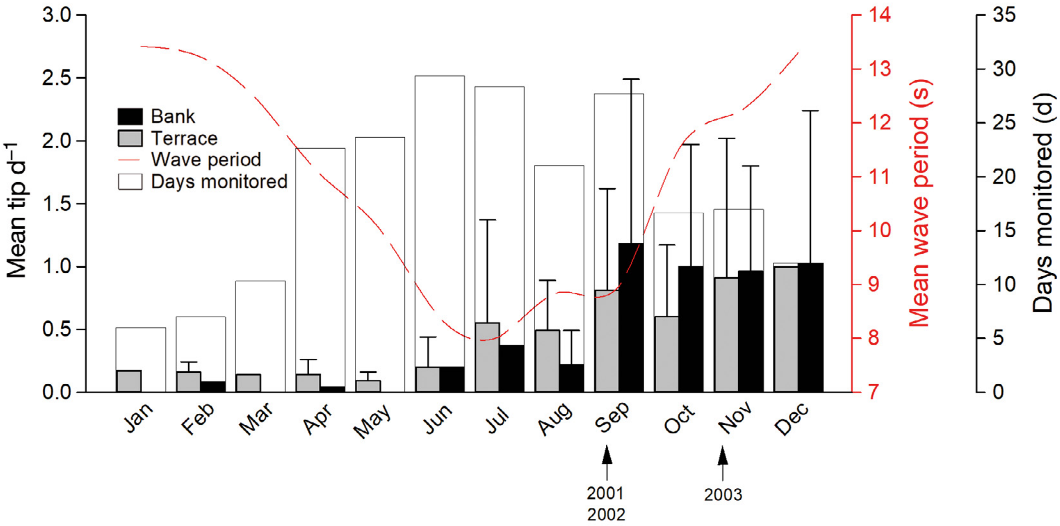

Fig. 4. Mean (+SD) tips d$^{-1}$ of electric rocks at the terrace and banks binned by month. Also shown is the seasonal change in the wave period (red dashed line) and the number of days monitored (white bar for days with a mean wave period <11 s); arrows on the *x*-axis show deployment of the electric rocks

tative of normal foraging behavior (Littnan et al. 2004). However, we need to determine how the seal's behavior and habitat visitation change seasonally. Recent advances in seal-mounted tags have improved the data resolution for seal foraging by integrating GPS positioning, accelerometer data, and imagery (Vance et al. 2021). Although this technology has been adopted for research on monk seals at French Frigate Shoals (Robinson et al. 2021), we still face limits on which seals can be instrumented and for how long. Relying on a year-round series of camera deployments on monk seals will include uncertainty about how the cumulative effects of instrumentation drag affect the seal's condition and behavior (Jones et al. 2013). Given the monk seal's endangered status, conservation efforts seek to balance the need for data collection while minimizing the disturbance to the species (Lowry et al. 2011). Our seal-mounted cameras provide a brief, high-resolution glimpse of the seal behavior that we use to identify complementary data collection methods to fill the identified information gaps. From the video, we know the type of habitat seals visit. Seals search rocks if they are present, so rather than using lots of seal tagging or seabed-mounted camera arrays, we instead exploit the seals' rock searching behavior. This strategy provides a less burdensome and inexpensive alternative to monitoring habitat visitation. Monk seals will likely use loose rock habitats like fishers use fish aggregation devices (Gooding & Magnuson 1967) or artificial reefs (Bohnsack 1989). They search broad areas for prey at sea, but on their way out and back, they deliberately stop and check for prey aggregating around static, fixed objects. Determining the relative contribution of this habitat to the seal's general feeding ecology and its importance to the viability of the seal colony is an area for future research. All the seals we instrumented were healthy and moved and searched rocks whenever they encountered them. We have no similar data for the seals doing poorly, making it difficult to comment on the relative energetic benefit of this feeding strategy.

### 4.2. Prey items found at the rocks

The fish identified in the dive surveys are diet items reported in previous monk seal foraging studies (Goodman-Lowe 1998, Longnecker et al. 2006, Longnecker 2010, Cahoon 2011, Iverson et al. 2011, Cahoon et al. 2013). Most of the species (59%) are found in shallow coral reef surveys (10 m) on the atoll barrier and lagoon patch reefs (DeMartini et al. 2002). This level of overlap between shallow and mesophotic fish taxa is consistent with findings from comparative studies of the Hawaiian reef ecosystem (Boland et al. 2022). For monk seals, even though the prey is abundant in the shallows close to their beach haulouts, they are harder to catch among reef structures than on the open bottom of the mesophotic slope. The individual rocks provide the seals a conspicuous target and a way to search less surface area and access a higher fish density. Even though the overall mean fish density was higher around the rocks, there was rock to rock variability in fish numbers seen by the divers. Varying levels of recruitment and periodic visits by seals that consume the settled prey influence the numbers of fish and invertebrate prey items the divers see on their surveys.

### 4.3. Monitoring with electric rocks

Having removed the effect of waves from the data, we assume that monk seals are the only animal that can move the weight of the 20.5 kg (11.5 kg underwater) electric rock and record a tip. Other animals (i.e. reef fish, octopus) routinely burrow in the sand bottom and move seafloor rubble much smaller than the weight of the electric rock. A species of wrasse called the rock turner *Novaculichthys taeniourus* lifts rocks to search for prey hiding underneath. However, at its largest size, it is only 30 cm (Randall 2007), too small to move the electric rock. The animal's body mass must be large enough to brace on the seafloor and lift the rock, a technique monk seals have mastered. The seals could flip the rocks completely over but mostly slid their heads under the rock to eat the fish from their concealment so that the fish would not flee the rock. This strategy is critical in situations where there are jacks or sharks present competing for the same prey item. More rock searching was evident from seals foraging in the presence of competitors (Table 1). The body mass of jacks and sharks escorting the seals is sizable, but these species' routine movement of large seafloor rocks is unreported. Based on the behavior exhibited by the sharks and jacks recorded in the video, they know prey hides around and under the rocks. However, they spend no time moving the rock and instead follow the seals and compete for the prey items once the seal tips the rock and flushes the prey from cover (Parrish et al. 2008).

The diurnal and seasonal patterns from the electric rock data are a starting point for future work looking at gateway habitats to augment monitoring strategies for monk seal foraging behavior. Seals visit rock habitats day and night, but there is more day activity at the banks. The pattern likely relates to the seal's immediate access to the nearby terrace from the atoll's beach haulouts vs. the hours of open ocean swimming required to visit the banks. Seals that travel to the banks are more likely to be engaged in more prolonged and directed systematic foraging, given the lack of an onsite beach resting location.

The skewed seasonal pattern in the year-long deployment of rocks showed more searches of electric rocks in the summer–fall than for the rest of the year. The pattern could be due to fouling bias; as rocks foul with time throughout the year, they may be less conspicuous to the seals and not searched at the same rate. However, even when fully fouled, there is still a post-winter increase in the daily search rate that approaches levels seen during the initial deployment of the rocks. The monk seals reproductive event likely influences the high searches in the summer–fall (Johnson & Johnson, 1984), when female seals haul out on the beach for 5–6 wk to give birth and nurse pups (Johanos et al. 1994). The number of seals on the beaches of Whale Skate and Trig sand islets increases from summer to November, associated with the mix of pupping, molting, and breeding (Johnson & Johnson 1984), keeping seals close to the atoll where they may be more likely to feed in nearby habitats. Once the reproductive season passes, the seals may shift their foraging to other habitat types. Satellite tag studies show that the depth and habitat targeted by individual seals can change greatly (Abernathy 1999, Stewart et al. 2006, Curtice et al. 2011). However, the positioning error and binned depth of dive records prevent us from making habitat-specific interpretations.

It is also likely that the prey recruiting to the rocks seasonally changes with the greatest fish density associated with the summer–fall reef fish recruitment pulse (Russell et al. 1977). Schroeder (1987) monitored the recruitment of Hawaiian reef fish to isolated sea floor objects (coils of wire deployed on the sand bottom of Midway lagoon) and found a daily recruitment rate between 0.73 and 1.76 post-larval reef fish in summer months. There are no similar estimates of reef fish recruitment for mesophotic habitat, but being outside the atoll and directly exposed to the passing oceanic scattering layer might increase the recruitment rate of some species (Sponaugle 2015).

More year-long deployments of electric rocks are needed to confirm the seasonal patterns in this preliminary data. Future work should update the electric rocks with contemporary accelerometer technology that would distinguish between different types of rock movements. In addition, deploying electric rocks should emphasize deep sites to reduce wave influence and maximize the monitoring window for monk seal searching behavior. The summit of Southeast Brooks Bank is an excellent monitoring gateway, given its deep summit and location between the atoll and the more expansive foraging grounds to the northwest. A game-changing technological advancement would be the development of a seawater passive integrated transponder (PIT) tag reader. An ability to read the PIT tags underwater means the electric rocks could monitor the visitation of the tagged population of monk seals for the entire year regardless of any wave influences. The PIT tag identification code would add all the demographic information (age, sex) about the visiting monk seals. The impact of these technological advances would significantly enhance our understanding of these patterns and help guide future research efforts.

Our event loggers, in the form of electric rocks, used the monk seal rock-searching behavior to monitor visitation to a portion of the seal's feeding grounds. Applying this approach to other marine mammal species depends on understanding their seafloor searching behavior and the landscape they forage in. Otters are known to move rocks as they search for food on the seafloor and are an obvious candidate should there be interest in this type of monitoring. As the improving technology used in marine mammal instrumentation studies expands, we expect future work to identify similar rock-searching behavior for other species. This type of work will reveal feeding strategies and foraging habitats and provide an opportunity to use seafloor instruments to monitor visitation and understand the relative importance of the habitat to the animal's foraging landscape.

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