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Evaluation of the Captive Care and Post-Release Behavior and Survival of Seven Juvenile Female Hawaiian Monk Seals (*Monachus schauinslandi*)

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Abstract

Extremely poor juvenile survival in the endangered Hawaiian monk seal (*Monachus schauinslandi*) is primarily caused by prey limitation and continues to drive the population decrease in the Northwestern Hawaiian Islands (NWHI). In 2006-2007, a pilot project was conducted to determine whether temporarily providing nutritional supplementation and protection from predation would enhance the survival of juvenile monk seals. Seven female seals, two of which were rare fraternal twins, were included in the captive care (CC) project. Six weanling seals gained weight commensurate with their duration in captivity, 89 to 297 d, with weight gains of 31 to 143% initial body weight, and were released at Midway Atoll. The seventh seal, a female yearling, died 23 d after being admitted from complications associated with malnutrition and stress. The CC and three control seals were instrumented with satellite-linked GPS dive recorders to monitor post-release behavior and survival as part of an assessment of the project's success. Satellite tags transmitted between 37 and 311 d. Initially, the CC seals foraged closer to shore, used less of the atoll, and dove to shallower depths (< 20 m) and for shorter durations (< 4 min) relative to the controls (> 60 m and > 4 min). Over the course of several weeks, most of the CC and control seals were foraging in a similar fashion. These results demonstrate that following a brief acclimation period, captive-fed monk seals are capable of foraging normally post-release. However, none of the CC seals were alive as 2-y-olds, whereas two of the control seals were alive in 2010 as 4-y-olds. Although post-release survival was poor in the current study, with a more suitable release location, an expanded captive-feeding program could be a useful tool to salvage the reproductive potential of Hawaiian monk seals in the future.

Key Words: captive care, post-release monitoring, juvenile survival, foraging behavior, Hawaiian monk seal, *Monachus schauinslandi*

Introduction

Prey limitation is one of the leading factors contributing to the poor juvenile survivorship of the endangered Hawaiian monk seal (*Monachus schauinslandi*; Banish & Gilmartin, 1992; Gilmartin et al., 1993; Craig & Ragen, 1999; Baker, 2008). Less than one in five monk seals currently survive to reproductive age with 1-y-old individuals having the greatest mortality rates (Baker & Thompson, 2007). The poor recruitment of juvenile seals to sexual maturity has led to the unsustainable population dynamic of an inverted age structure pyramid skewed toward older seals (Johnson et al., 1982; Johanos & Baker, 2007). Consequently, the Hawaiian monk seal population in the Northwestern Hawaiian Islands (NWHI) continues to decrease at a rate of ~4%/y (Carretta et al., 2007). With fewer breeding females being recruited into the population, the current decrease in numbers of Hawaiian monk seals will likely accelerate.

With the continued population decrease in the NWHI, management agencies are examining multiple techniques to increase survival rates. The Hawaiian Monk Seal Recovery Plan highlights that the first priority for recovery is to enhance female, particularly juvenile, survival (National Marine Fisheries Service [NMFS], 2007). However, the persistence of insufficient prey availability and the risk of predation for young monk seals are incompatible with improved juvenile survivorship, and the potential to mitigate these causes of mortality in the NWHI is improbable (NMFS, 2007). In contrast to the inability to reverse *in situ* conditions, temporarily caring for wild individuals in a captive environment is one way in which the effects of food limitation and predation can be mitigated.

The rehabilitation of marine mammals followed by their release is well-documented, although the value of these rehabilitation programs is contentious (Wilkinson & Worthy, 1999; Moore et al., 2007). However, the reintroduction of captive-fed individuals back into the wild has direct conservation implications for endangered and threatened species (Kleiman, 1989; Moore et al., 2007). For example, reintroduction programs saved the California condor (*Gymnogyps californianus*) from extinction (Snyder et al., 1996) and have been implemented to promote the population recovery of the Florida manatee (*Trichechus manatus latirostris*; Reynolds, 1999) and the southern sea otter (*Enhydra lutris*; Nicholson et al., 2007).

Captive care (CC) and reintroduction efforts also have been used to improve juvenile survival rates in Hawaiian monk seals in an effort to restore the depleted NWHI population (Ragen & Lavigne, 1999). Thirty-two weanling female seals were held in shoreline enclosures at Kure Atoll and fed live reef fish and invertebrates for varying periods between 1981 and 1991. These seals lost on average 0.26 kg/d but experienced similar first-year survival after release as the wild seals (85%). In addition, from 1984 to 1995, 103 juvenile seals were collected from French Frigate Shoals and rehabilitated at Midway and Oahu Islands. Sixty-nine of these seals were released at Midway and Kure Atolls, whereas 18 died in rehabilitation and 16 were placed in permanent captivity. The 13 seals released at Midway Atoll had the poorest survival: 23% survived 1 y post-release and 0% survived 2 y post-release. Rehabilitation efforts ceased in 1995 when 10 of the 12 immature monk seals included in the CC program contracted an eye condition of unknown etiology that led to partial blindness (NMFS, 2007). In 2003, a single prematurely weaned female pup was held in a shoreline pen at Midway Atoll for 34 d but died after release before reaching 1 y of age in the wild.

A Hawaiian monk seal CC program was again resumed in 2006-2007 when seven juvenile female monk seals were temporarily held in captivity to provide nutritional supplementation and protection from predation over the winter, a period of greatest juvenile mortality (NMFS, unpub. data), prior to reintroduction into the wild. An important component of this project was monitoring the post-release behavior and survival of the reintroduced seals compared to appropriate controls, which is critical to the assessment of the efficacy of any rehabilitation program (Kleiman, 1989; Le Boeuf, 1996; Dendrinos et al., 2007). The study objectives were twofold: (1) to reinitiate a Hawaiian monk seal CC program and determine whether juvenile seals could be successfully fed in captivity to increase body weight, be released, and forage normally after release; and (2) to determine if a CC program would enhance the survivorship of juvenile Hawaiian monk seals and thereby salvage the reproductive potential of this endangered species.

Materials and Methods

Captive Care

Seven juvenile female monk seals were captured at Midway Atoll and brought into captive care (Table 1). The seals selected for inclusion in the CC program were weanling or yearling female seals that were in good health, though some were undersized at the time of admission. Health status was assessed using hematology, serum biochemistry, and physical examination. Two of the CC seals were undersized, rare fraternal twins (PO22 and PO26) that were captured 11 d after weaning and flown to Honolulu, Hawaii. The twins were held in a single enclosure under strict quarantine at Kewalo Research Facility (KRF) from 27 May to 17 October 2006. The KRF enclosure was 58 m^2 with dry resting area around a 6-m diameter, 1.2-m deep pool on an open saltwater system. Weekly fecal coliform counts were performed on inflow and pool water samples using the membrane filtration technique (Hawaii Food & Water Testing Laboratory, Honolulu, HI, USA). Inflow counts were always < 1/100 mL. When pool counts exceeded 1,000/100 mL, the pool was drained, sanitized with a 10% bleach solution, and refilled, and the water was retested the following day. The entire enclosure was sanitized with 10% bleach weekly. Weight, axillary girth (AG), and dorsal standard length (DSL) measurements were determined weekly, and the appearance of the seals' eyes was monitored through weekly digital photographs and veterinary examination.

The twins were transported back to Midway Atoll in October 2006. All young-of-the-year female seals still alive at Midway in October (n = 3) were captured for inclusion in the CC program, regardless of size (Table 1). Additionally, one undersized female yearling was brought into CC in October, and one undersized weanling female seal was brought into CC in late December 2006, after not being sighted on Midway since August at the end of the population monitoring season. The seals were held in shoreline net pens on Cargo Beach, Sand Island, with the twins being held in a separate pen for a 30-d quarantine period. The net pens were approximately 4.5 m apart and at least 9 m wide × 39.5 m long with a fourth to a third of this being water area that was 1 to 1.5 m deep. Net pens were repaired daily due to sand movement and wave action. To decrease the chances of the CC seals attempting to escape through an

underwater hole in the fencing, risking potential entrapment and drowning, the seals were penned up on land from 1830 to 0700 h each night from 2 November 2006 to 16 March 2007. One tsunami warning and a severe northwest swell required overnight evacuations of the seals from the beach pens to the island interior, with the CC seals being held in cages (two seals held together in 2.4 m × 1.2 m × 1 m cages or a single seal held in 1.5 m × 0.6 m × 1 m cages) that were manually lifted onto a flatbed truck. Midway was selected as the captive care and release site for this study because of the existing infrastructure at this site; in 2006-2007, Midway was the only atoll in the NWHI accessible by airplane, which allowed personnel and supplies to be transported on weekly flights.

The monk seals were fed human food-quality, thawed, previously frozen Pacific herring (*Clupea pallasii*) two to three times per day and were force-fed until they learned to eat dead herring on their own. All the CC seals demonstrated the ability to feed on larger live reef fish, which were introduced into the holding pens on five separate occasions, but they largely ignored the small threadfins (*Polydactylus sexfilis*) that moved freely in and out of the pens. Multivitamin supplements (one "Pinnivite" per seal; Mazuri, Purina Mills, Inc., St. Louis, MO, USA) were administered daily, and the seals were weighed weekly on Midway after 15 November 2006. Antibiotic treatment was provided on two instances due to gastrointestinal symptoms: (1) PO22 was prescribed Dual-Pen (TechAmerica, Kansas City, MO, USA; 1 mL/10 kg, IM, eod) for 2 d (19 to 21 February 2007), and (2) PO42 was prescribed enrofloxacin (5 mg/kg, IM/PO, sid) for 7 d along with Dual-Pen (1 mL/10 kg, IM, eod) for 4 d and amoxicillin (12 mg/kg, PO, bid) for the following 6 d (8 to 17 January 2007). The CC seals were treated inconsistently, due to logistical constraints, with anti-helminthic drugs for gastrointestinal cestodes (5 mg/kg praziquantel administered PO, sid for 2 d) and/or nematodes (10 mg/kg fenbendazole administered PO, sid for 3 d). Three CC seals (PO22, PO26, and PO46) were treated with praziquantel then fenbendazole 2 to 3 d later at these dosages, and two seals (PO40 and PO48) were given praziquantel only in March 2007. PO42 was given a single oral dose of 10 mg/kg praziquantel on 19 January 2007.

Tagging of Captive Care and Control Seals

The six weanling monk seals were released on 19 and 22 March 2007 when the seals had experienced significant size increases; were approximately 1-y-old; and, therefore, were expected to be more likely to survive in the wild (Baker & Thompson, 2007; Baker, 2008). Prior to release, the CC seals were handled as described previously for instrumentation and biological sampling (Baker & Johanos, 2002). A satellite-linked time-depth recorder (SLTDR) with global positioning system (GPS) technology (Mk10-AF tag; Wildlife Computers, Redland, WA, USA; 64 g in air) and VHF radio-transmitter (Advanced Telemetry Systems, Isanti, MN, USA; 27 g in air) were attached to the dorsal pelage using Devcon 10-Minute Epoxy resin (ITW Devcon, Danvers, MA, USA).

Only three monk seals from the 2006 cohort that were not included in the CC program were alive at Midway in March 2007—one female born at Kure Atoll (KO76) and two males born at Midway (PO12 and PO20). Because gender and birth site are not expected to affect the survival or foraging behavior of juvenile monk seals at Midway Atoll (Stewart, 2004; Stewart & Yochem, 2004a; Parrish et al., 2005; Baker & Thompson, 2007), these three seals were designated as "controls." In March 2007, the controls were captured for biological sampling and instrumentation with a Mk10-AF transmitter (Baker & Johanos, 2002).

Each Mk10-AF tag was programmed to transmit 250 times per day while NOAA satellites were in view. After the wet/dry sensor was dry for ≥ 10 min, the instrument switched to "haul-out mode," and transmissions paused when the tag was dry for greater than 2 h. In addition to locations provided by the *Argos* Data Collection and Location Service (DCLS), the Mk10-AF tags were programmed to collect Fastloc™ GPS satellite locations (Wildtrack Telemetry Systems Ltd., Leeds, England) at 10-min intervals during seal surfacings, with a maximum of four successful and three failed transmissions per hour. Transmitted data also included dive depth and duration summaries (10-s sampling interval) binned into 14 frequency histograms for four 6-h periods of the day with start times: 0600, 1200, 1800, and 0000 h local time (GMT – 10 h). Dives < 2 m and 1 min in duration were ignored.

Post-Release Monitoring and Data Analysis

The diving behavior, movement, and survival of the CC and control seals were qualitatively compared. The VHF transmitters allowed for real-time tracking of the CC seals to visually assess and photo-document body condition, potential injuries, molt status, and tracking device condition for each CC seal at least once per week. The survival of the CC and control seals was determined through post-release satellite tracking and visually resighting the seals on surveys that are conducted throughout the Hawaiian Archipelago each year. The probability of sighting a seal that is alive in a given year in the NWHI is typically > 90%; therefore, if a seal

was not sighted again, it was considered to be dead (Baker & Thompson, 2007).

To describe the at-sea movement and marine habitat use by the CC and control seals, filtered Fast-GPS location data were overlaid on seafloor bathymetric data obtained from the University of Hawaii at Manoa, Pacific Island Benthic Habitat Mapping Center (retrieved from www.soest.hawaii.edu/pibhmc). Erroneous locations were removed using a transit speed (TS) and turn angle (TA) filtering algorithm (Freitas et al., 2008). A threshold TS of 2 m/s was used (Parrish & Abernathy, 2006). Locations also were removed if the TA and incoming straight-path distance associated with each location exceeded (1) TA > 145° and distance > 10 km, (2) TA > 155° and distance > 5 km, and (3) TA > 165° and distance > 2 km. Only Fast-GPS locations were used because, in contrast to the *Argos* locations, these locations are more accurate, with 95% of the acquisitions having error estimates of < 140 m when a signal is received by at least five satellites, and they are collected on a more regular basis throughout the day (Bryant, 2007; Collecte Localisation Satellites [CSL], 2008).

In addition, dive summaries sent via the *Argos* network were used to qualitatively compare the foraging behavior and effort of the CC and control seals. The proportion of dives to varying depth and duration bins was calculated over 2-wk intervals for the first 12 wks following instrumentation. These proportions were determined for each CC seal separately and combined for the three control seals. The number of dives in each of the 14 frequency histograms were pooled into the following depth bins: < 20 m, 20 to 60 m, 60 to 100 m, 100 to 120 m, and > 120 m. Dive durations > 8 min were pooled, and 1-min histogram bins for durations < 8 min also were pooled into 2-min bin increments: < 2 min, 2 to 4 min, 4 to 6 min, 6 to 8 min, and > 8 min.

Results

Captive Care

Seven juvenile female monk seals were held in captive care for 23 to 297 d (Table 1). During this time, daily food intake by weight was maintained at approximately 6% of the seal's body weight. Whereas the release weight of the six weanling seals was 31 to 143% greater than initial body weight, the single yearling seal (PV02) experienced marked weight loss (Table 1; Figure 1). PV02 exhibited behavioral signs of stress throughout captive holding, manifested as constant stereotypic swimming and refusal to eat dead herring, and died 23 d after being admitted from severe malnutrition and adrenal exhaustion diagnosed by adrenocortical hyperplasia observed on histology. The CC seals did not exhibit behavioral signs of stress as a direct result of handling events, including the two evacuations.

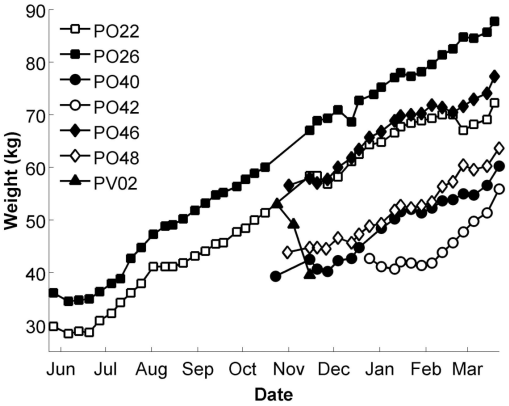

Figure 1. Weights for the seven female monk seals included in the 2006-2007 CC project; no weights were collected at Midway Atoll from each seal's admit date until 15 November 2006 with the exception of a weight that was collected on PV02 on 4 November 2006.

Table 1. Morphometric measurements at the time of admittance in 2006—weight, axillary girth (AG), and dorsal standard length (DSL)—and percentage total body weight change for the six weanling (W) and one yearling (Y) CC female seals

Seal ID	Age class	Admit date	Weight (kg)	AG (cm)	DSL (cm)	Total weight change (%)	Duration of CC (d)
PO22	W	27 May	29.8	82.0	111.0	142.6	297
PO26	W	27 May	36.1	89.0	109.0	142.9	297
PO40	W	23 October	39.3	85.0	127.0	53.2	150
PO42	W	24 December	42.7	87.0	132.0	30.9	89
PO46	W	1 November	56.6	95.0	141.0	36.6	138
PO48	W	31 October	43.9	95.5	126.5	44.9	142
PV02	Y	23 October	53.0	90.5	146.0	-25.5	23

The normal care of the CC seals was frequently compromised and disrupted by the weather and dynamic nature of beach topography, especially during the winter. All six weanling seals experienced periods of weight loss during captive care that were not associated with signs of ill health (Figure 1). Instead, weight loss in the CC weanling seals often was associated with escapes from the pens and, more frequently, periods of low activity and inappetence resulting from warm weather or lack of a sufficient swim area. For example, unusually warm weather from 18 to 22 November 2006 depressed the appetites of PO22, PO40, and PO46. In addition, from October to December 2006, sand erosion at the pen location created large holes beneath the fencing, allowing the seals to escape on six separate occasions, with the longest escape lasting 4 d (PO26 escaped from 10 to 13 December 2006). However, from January to March 2007, sand deposition on Cargo Beach continually filled in the swim areas of the pens, prompting constant rebuilding of the pens' perimeter. In addition, the winter weather may have precipitated PV02's death; in the week preceding her death, cold, stormy weather, which she likely was more susceptible to because of her diminished fat reserves, coincided with an observed decrease in PV02's external body temperature.

Post-Release Monitoring

Initially after reintroduction into the wild, the body condition of the CC seals visibly deteriorated. Whereas two of the six seals released from CC continued to lose weight, the weight of the other four CC seals appeared to stabilize or improve within 4 wks of release (Table 2). The body condition of the control seals remained stable throughout the monitoring period. One of the twin seals (PO22) left Midway Atoll 37 d after release and swam > 90 km northwest to Kure Atoll, where she was resighted in medium body condition until the end of the population monitoring efforts in August 2007 (Table 2; Figure 2d). The other twin seal (PO26) also was alive at Midway Atoll at the end of the seasonal monitoring effort but was in emaciated body condition (Table 2). However, these twin monk seals were not resighted in subsequent years at any of the NWHI and therefore died before reaching age 2. The other four CC seals disappeared less than 15 wks after release in medium to thin body condition and also died before reaching 2 y of age (Table 2). The three control seals were resighted in medium body condition in 2008, and two of the three were still alive in 2010 as 4-y-olds (Table 2).

The six CC seals were tracked using satellite telemetry for 37 to 146 d, and the three control seals were tracked for 74 to 311 d (Table 2). On average, only 3.38 ± 1.51% of the Fast-GPS locations for each seal were removed after filtering. Based on the at-sea locations and dive summaries, all the control seals foraged on the shelf to the southeast of Midway Atoll and primarily dove to depths in excess of 60 m for more than 4 min in duration (Figures 2a-c, 3 & 4). In comparison to the control seals, the movements of the CC seals were more widely dispersed around Midway Atoll, with greater use of the shallow lagoon habitat immediately following release (Figures 2a-c). However, similar to the control seals, the at-sea movement of PO22 at Kure Atoll was primarily on the southeastern shelf habitat (Figure 2d). Four of the six CC seals, including PO22, also demonstrated large exploratory movements over deep

Table 2. Weaning dates, with ranges provided when the exact weaning date was unknown, and post-release resight and satellite tracking summary for the CC and control monk seals; seal body condition (BC) at the time of the last sighing for each seal was classified as medium (M; round shape with no joint bones visible and curved from pelvic girdle to tail), thin (T; points of hips and shoulders visible, slightly sunken neck, and flattened from pelvic girdle to tail), or emaciated (E; sunken neck and prominent ribs, spine, shoulder blades, and pelvic bones). All seals weaned in 2006 and were last sighted at Midway Atoll, except PO22 and PO20 that were last sighted at Kure Atoll. The satellite tag was removed from PO22 prior to termination of transmissions.

Seal ID	Weaning date	Last sighting date (BC)	Last satellite transmission date	Satellite tracking duration (d)
PO22	16 May	22 August 2007 (M)	18 July 2007	122
PO26	16 May	18 August 2007 (E)	11 August 2007	146
PO40	27 June	23 April 2007 (M)	27 April 2007	37
PO42	12-14 July	7 June 2007 (M)	13 June 2007	84
PO46	21-22 July	21 June 2007 (T)	28 June 2007	102
PO48	3 August-31 October	18 May 2007 (M)	19 May 2007	56
PO12	28 January-21 February	20 September 2008 (M)	8 June 2007	74
PO20	23-25 April	30 July 2010 (M)	26 January 2008	311
KO76	8 July	29 June 2010 (M)	25 January 2008	304

water habitat (> 200 m), whereas the tracks of all three control seals remained within the 200-m isobath during the satellite tracking period.

In addition, the diving activity of the CC seals was initially restricted to shallow waters (< 20 m; Figure 3) and short durations (< 4 min; Figure 4). The diving behavior of the CC seals progressively became more similar to the control seals, though the onset of deeper, longer duration diving on the outer reefs and slope varied among the CC seals independently of the timing of weaning (Table 2; Figures 3 & 4). Two of the CC seals (PO26 and PO46) exhibited prolonged shallow, short duration diving, with greater than 80% of all dives for PO46 < 20 m in depth 14 wks post-release (Figures 3 & 4). The CC seal (PO42) that was admitted in late December, 2 mo after the other CC seals, attained normal foraging behavior more rapidly than the other CC seals (Table 1; Figure 3).

Discussion

The criteria used to evaluate the success of a captive care and release program depend on the specific goals of the CC program, species' status in the wild, and conditions at the release site (Kleiman, 1989). Because one of the objectives of this study was to reinitiate a Hawaiian monk seal CC program, the first measure of success for this program was the successful rehabilitation, including the increase in body weight, of the CC seals. Based on the study objectives, the reintroduction of healthy, robust individuals into the wild and the independent foraging success of the captive-fed seals also were used to assess the efficacy of the 2006-2007 CC program. With the endangered status of the Hawaiian monk seal, the success of this program ultimately could be measured by evaluating the survival and reproductive contribution of the CC seals to the wild population (Le Boeuf, 1996). However, the survival and

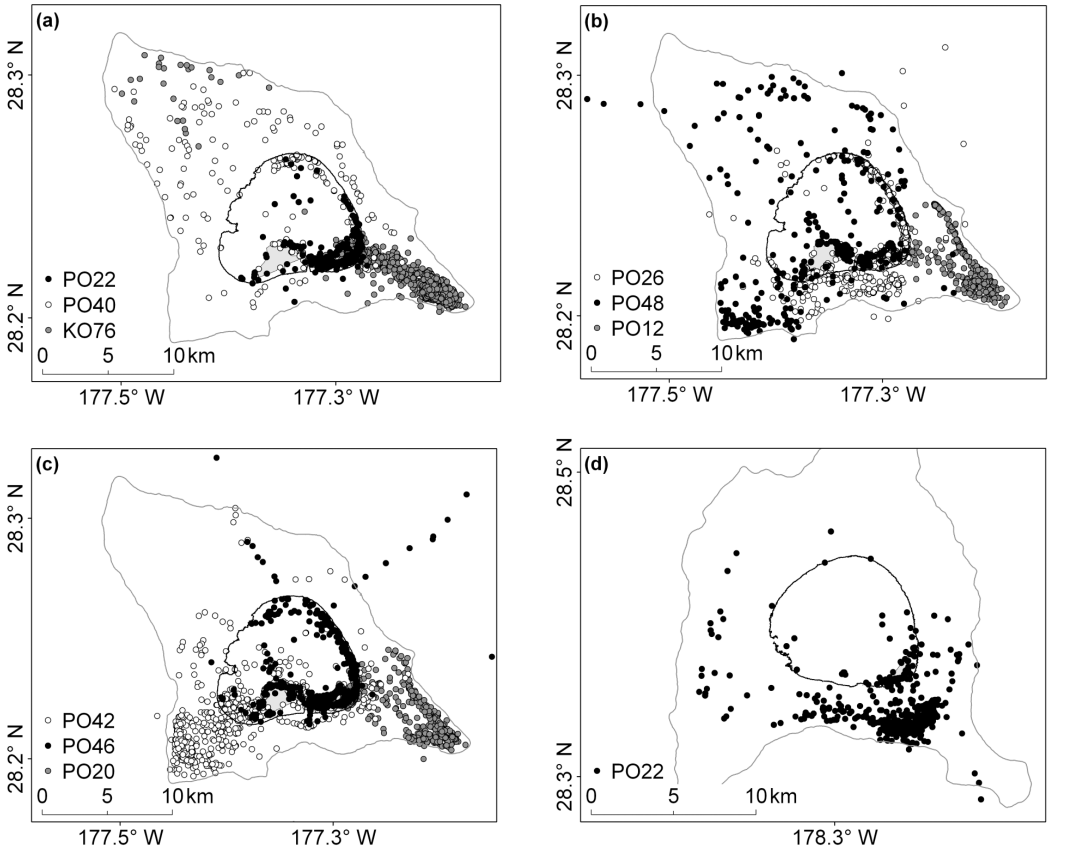

Figure 2. Filtered Fast-GPS locations for the six weanling CC seals (black- and white-filled circles) and three control weanling seals (gray-filled circles) at Midway Atoll (a-c) and Kure Atoll (d); the 6-m isobath (black line) approximates the outer extent of the atoll lagoons. Land = light-gray shading and 200-m isobath = gray line.

reproduction of reintroduced animals relative to appropriate controls cannot always be used to evaluate the success of a CC program, particularly when there is a lack of suitable habitat or the environmental factors leading to the population decrease persist at the release site (Griffith et al., 1989; Kleiman, 1989).

With the exception of the single yearling seal, the captive-holding period of this study was successful in that the captive-fed weanling seals were released back into the wild in excellent health and body condition. During the 1981 to 1991 CC efforts at Kure Atoll, young monk seals were collected shortly after weaning; fed NWHI reef species until the late-summer, a time when weight loss is typically observed in monk seals; and lost significant amounts of weight throughout captive holding (Kenyon & Rice, 1959; NMFS, 2007). In contrast, the twin seals included in this study, similarly collected soon after weaning, and the other CC seals admitted later in the year experienced marked weight gains, likely a result of the high fat content of their herring diet. This demonstrates that a high-fat diet is essential to promote rapid weight gains in captive-fed monk seals. Although it is important that young CC seals demonstrate the ability to capture and feed on live fish prior to release, the CC seals in this study had limited exposure to live reef fish to better quantify the amount of fish consumed and to ensure their diet was primarily comprised of a non-native fish with greater caloric value to maximize weight gains. Furthermore, only two instances of ill health (mild gastrointestinal infection) occurred in the CC seals during almost 300 d of captive holding. Thus, no medical conditions arose that would have precluded release back into the wild, such as ocular lesions, which have occurred in other captive monk seal efforts (NMFS, 2007).

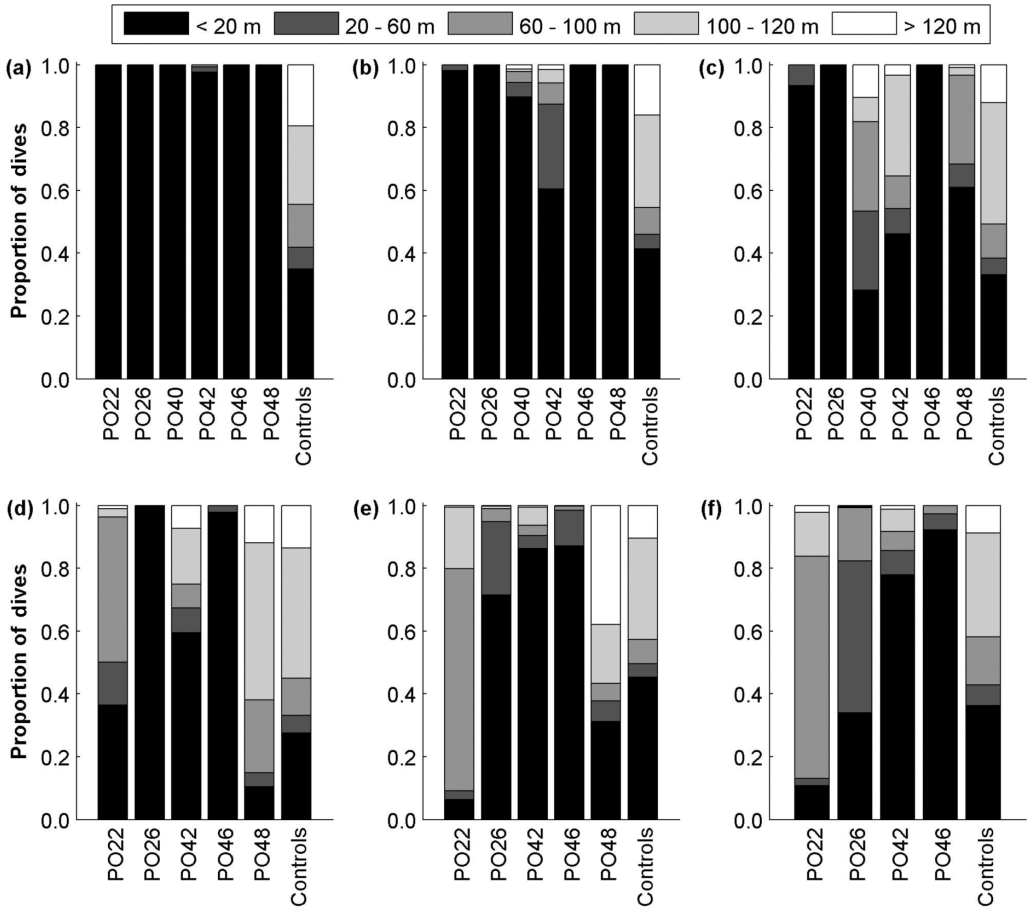

Figure 3. Proportion of dives to varying depth bins (a) 1-2, (b) 3-4, (c) 5-6, (d) 7-8, (e) 9-10, and (f) 11-12 wks post-release for the CC and control seals

Other areas of the captive-holding period of this study were less successful. The behavior and death of the yearling seal PV02 and past Hawaiian monk seal CC efforts indicate that older juvenile seals (age 1 to 3 y) may be more susceptible to stress in captive care (Baker & Littnan, 2008). PV02 exhibited signs of stress regardless of the proximity of humans or other CC seals; thus, captive-holding itself was likely the primary cause of stress in the yearling seal, though handling events associated with feedings and administering medical treatments may have contributed, especially as her condition deteriorated. In addition, the changing beach environment, winter weather, and remote location of Midway Atoll frequently compromised the quality of care necessary to adequately feed, treat, and shelter the CC seals, particularly when medical complications associated with stress and illness arose.

The post-release foraging behavior and body condition of the CC seals relative to the control seals was examined to evaluate the independent foraging success of the CC seals. Immediately following their release, the CC seals had limited foraging dispersion with shallow-water diving. Previous foraging research has shown that recently weaned Hawaiian monk seal pups typically have more restricted foraging ranges and dive to shallower depths than older individuals (Stewart, 2004; Stewart & Yochem, 2004a, 2004b; Littnan et al., 2006). Furthermore, it is not unusual for rehabilitated juvenile seals to demonstrate a delayed development of normal foraging behavior post-release (Vincent et al., 2002; Dendrinos et al., 2007). Therefore, the period immediately following the release of the CC seals was likely an acclimation period analogous to the post-weaning period in wild seals (Harvey, 1991). In

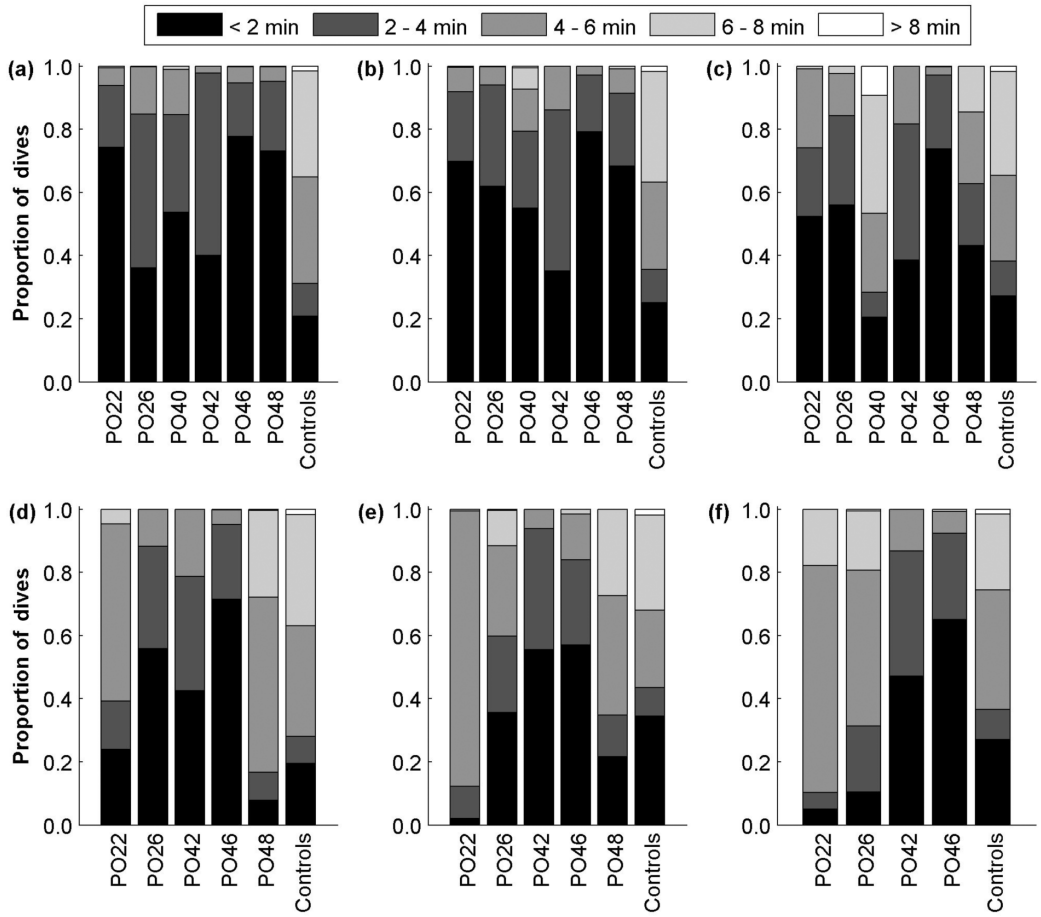

Figure 4. Proportion of dives to varying duration bins (a) 1-2, (b) 3-4, (c) 5-6, (d) 7-8, (e) 9-10, and (f) 11-12 wks post-release for the CC and control seals

contrast, 7 wks post-release, four of the CC seals had expanded their foraging ranges beyond the shallow lagoons of the atolls and were primarily using the seamount slope in water depths > 60 m. Similar foraging behavior was observed in the three control seals and has been previously documented in juvenile monk seals at Midway and Kure Atolls (Stewart & Yochem, 2004a, 2004b), which indicates that these CC seals successfully developed normal foraging behavior in the wild. Additionally, the timing of admittance into captive care appears to affect how quickly CC seals achieve normal foraging behavior because the CC seal admitted in late-December developed normal foraging behavior more rapidly. With the post-release acclimation period analogous to the post-weaning period in wild seals, the CC seals initially lost weight after being released, which was not surprising because post-weaning weight loss is typical of phocids as they undergo the transition to independent foraging (Reiter et al., 1978; Worthy & Lavigne, 1983). The weights of three of the CC seals that remained at Midway and the one CC seal that migrated to Kure Atoll stabilized or improved within 1 mo of release into the wild, which along with the normal movement and diving activity of these CC seals, indicates the development of effective independent foraging. In contrast, the continued post-release weight loss in two of the CC seals, which also demonstrated prolonged periods of acclimation with one of these seals rarely foraging beyond the shallow lagoon, is indicative of a failure to acquire the foraging skills necessary to survive without nutritional supplementation and/or the inability of the environment to nutritionally support these seals.

Whereas two of the three control seals were alive in 2010 as 4-y-olds, none of the CC seals survived 1 y post-release and, consequently, never reproduced. The cause of death for the two CC seals at Midway that failed to acquire the foraging skills necessary to survive in the wild was likely linked to their deteriorated nutritional state, which ultimately led to starvation or an increased risk of predation (Heithaus et al., 2008). However, the three CC seals that remained at Midway Atoll and developed effective independent foraging skills disappeared at sea in good body condition, and the termination of satellite transmissions coincided with the timing of the last sighting and radio transmission in each case. It is therefore probable that these three seals died as a result of catastrophic events at sea, most likely predation by a large shark (e.g., tiger shark [*Galeocerdo cuvier*]). The single CC seal that migrated to Kure Atoll was last sighted in good body condition 5 mo post-release but died over the winter when there was no monitoring effort. Consequently, the cause of death for this seal could not be reasonably deduced. Because juvenile mortality has been linked to experience, with naïve individuals being more susceptible to predation and less adept at locating and capturing prey (Curio, 1993; Biggins et al., 1999; Vargas & Anderson, 1999), the relative naiveté of the CC seals may account for the different survival rates between the captive-fed (0% alive 1 y post-release in 2008) and control seals (100% alive in 2008). However, this difference in survivorship also may be an artifact of the limited sample sizes. If captive-care status is disregarded, only three of the 13 weaned Midway-born seals from the 2006 cohort survived to age 2 (23%), which is comparable to juvenile survival rates at Midway Atoll over the last 10 y with survivorship to age 2 ranging from 0 to 27% (NMFS, unpub. data). The poor post-release survivorship of the CC seals in this study also was similar to that observed during the Hawaiian monk seal CC efforts of the 1980s and 1990s at Midway. Therefore, high juvenile mortality is not unique to the CC seals included in this study, and the ability of the CC seals to successfully forage independently in the wild was not the primary factor controlling post-release survival.

Rather, the success of reintroduction programs has been tightly linked to the release site choice and the mitigation of the environmental factors, such as the availability of suitable habitat and risk of predation, that originally led to the population decrease (Brambell, 1977; Griffith et al., 1989; Kleiman, 1989). Indeed, the NWHI are an apex predator-dominated marine ecosystem (Sudekum et al., 1991; Friedlander & DeMartini, 2002; Parrish et al., 2008) with decreased productivity (Polovina et al., 1994; Baker et al., 2007). Along with juvenile mortality caused by prey limitation, predation of juvenile monk seals by large sharks appears to be substantial in the NWHI as suggested by the inferred cause of death for at least three of the CC seals and through field observations, particularly at Midway and Kure Atolls (NMFS, 2007). Therefore, the poor post-release survival of the CC seals included in this study likely was caused by the *in situ* environmental conditions at the release site that continue to drive the population decrease.

Although the captive-holding period of this project was successful as the weanling seals gained significant weight, until the intrinsic environmental conditions become more favorable, captive-fed seals released at most sites in the NWHI will likely experience poor post-release survival. In contrast to the NWHI, the Main Hawaiian Islands (MHI) appear to offer an improved probability of survival for juvenile monk seals and sufficient food resources to support an increasing population trajectory (Baker & Johanos, 2004; Baker et al.,

2011). Along with selecting a more suitable release site, such as the MHI, for captive-fed seals, a dedicated animal care facility would mitigate many of the factors that compromised the quality of care provided to the CC seals included in this study, and therefore an improved level of treatment and care could likely be provided. There also may be some advantage to allowing monk seals to forage for longer periods prior to being brought into captive care because these seals may attain normal foraging behavior more rapidly and be less naïve to predators, which also could lead to an increased probability of survival. Whereas 1- and 2-y-old monk seals in the NWHI have the greatest mortality rates, survivorship improves dramatically after these seals reach ages 3 to 4 (Baker & Thompson, 2007). Consequently, it may be advantageous to include 2-y-old seals, which are returned to the wild around age three when they are expected to experience greater natural survivorship and are more likely to survive to reproduce, in future CC efforts. However, with the greater susceptibility of older juvenile seals to stress in captive care, a dedicated animal care facility for monk seals and careful consideration and implementation of stress mitigation techniques would be imperative. Thus, with an appropriate release site or age at release, and a more controllable holding facility that improves the quality of animal care, an expanded CC program may be a useful tool to salvage the reproductive potential of Hawaiian monk seals in the future.

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