Biological Conservation 144 (2011) 2692–2701

Contents lists available at SciVerse ScienceDirect

Biological Conservation

journal homepage: www.elsevier.com/locate/biocon

Translocation as a tool for conservation of the Hawaiian monk seal

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ARTICLE INFO

Article history:
Received 17 February 2011
Received in revised form 19 July 2011
Accepted 25 July 2011
Available online 27 August 2011

Keywords:
Translocation
Relocation
Hawaiian monk seal
Survival
Dispersal

ABSTRACT

The deteriorating demographic status of the endangered Hawaiian monk seal has motivated renewed and expanded proposals for conservation action, including translocation of seals to improve survival. Over the past three decades, numerous monk seal translocations have been conducted with a variety of objectives, including mitigating shark predation and conspecific male aggression, reducing human–seal interactions, and taking advantage of favorable foraging habitats to improve survival. Here, we analyze our cumulative experience with translocation of Hawaiian monk seals. We found a strong correlation between the time seals remained in the vicinity of the release site and their age. Recently weaned pups (with little or no at-sea foraging experience) exhibited high fidelity to release sites commensurate with that shown by untranslocated pups to their birth location. In contrast, juvenile and adult seals tended to stray from their release locations farther and sooner. Nevertheless, when 21 adult male seals were moved more than 1000 km from Laysan Island in the Northwestern Hawaiian Islands (NWHI), to the main Hawaiian Islands (MHI), they subsequently dispersed among the MHI; however, only one was observed to return to the NWHI. Translocated seals appeared to survive at rates comparable to seals native to the release site. Outcomes suggest that in most cases the intended objectives of translocations were achieved. Except for one notable case, translocations within the MHI to arrest human–seal interactions were mostly unsuccessful. These findings will be essential for informing successful large-scale translocation plans in the future.

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1. Introduction

The "IUCN Guidelines for Reintroduction" (IUCN, 1998) define translocation as "*deliberate and mediated movement of wild individuals or populations from one part of their range to another.*" Translocation has long been used as a wildlife management tool to achieve a variety of aims, including conservation, augmenting game populations, and resolving human–wildlife conflict (Fischer and Lindenmayer, 2000). Despite the history and frequent use of translocation, until recently information about the outcomes of translocation programs have been somewhat inaccessible, or have not typically been designed or analyzed in a statistically robust fashion (Fischer and Lindenmayer, 2000; Armstrong and Seddon, 2007). Fortunately, this situation has improved, as evidenced by numerous published studies. These include modeling approaches to improve translocation program design (Armstrong and Ewen, 2001; Dimond and Armstrong, 2007; Gusset et al., 2009; Decesare et al., 2011; van Houtan et al., 2010), and statistical analysis of translocation program success, whether the goal was conservation (Molony et al., 2006; Miskelly et al., 2009; Van Houtan et al., 2009; Oro et al., 2011) or resolving human–wildlife conflict (Bradley et al., 2005; Pinter-Wollman et al., 2009; Athreya et al., 2010). These studies report on experience with a wide variety of taxa. However, translocation has rarely been applied in marine mammals. Sea otters (*Enhydra lutris*) are the exception, having been reintroduced to several locations ranging from Alaska to southern California (Jameson et al., 1982; Estes, 1990; Rathbun et al., 2000). We know of no other marine mammal conservation efforts, published or not, that have involved translocations. Here, we report on the first analysis of translocation for a pinniped species, the Hawaiian monk seal (*Monachus schauinslandi*). Moreover, the long-term mark-resight information available for this species affords a rare opportunity to closely track translocation outcomes in terms such as survival and post-release dispersal.

The Hawaiian monk seal is an extremely endangered species with slightly more than 1000 individuals scattered amongst numerous subpopulations throughout the 2600 km-long Hawaiian Archipelago (Carretta et al., 2009, 2011). The overall number of monk seals is declining by approximately 4.5% $year^{-1}$, as a result of a variety of identified causes, including food limitation, shark predation, conspecific male aggression, entanglement in derelict

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0006-3207/$ - see front matter Published by Elsevier Ltd.
doi:10.1016/j.biocon.2011.07.030

marine debris, drowning in gillnets, and, recently, intentional killing by humans. The recently revised Recovery Plan for the Hawaiian monk seal recommends approaches to staunch the species' decline through a variety of actions. Among the proposed actions is to "*Enhance survival by translocating juvenile female seals to areas of higher survival probability*" (National Marine Fisheries Service, 2007). During the past three decades, numerous Hawaiian monk seals have been translocated to achieve various goals. Here, we present a critical evaluation of past experience as a prerequisite to developing new and expanded translocation programs for this species. We focus on cases where seals were moved a wide range of distances and released after varying, but typically brief, periods of captivity usually associated with transport. A distinctly different process involves bringing seals into captivity for an extended period of care and rehabilitation, followed by release back into the wild, typically at a site other than where captured. This latter procedure is reviewed by Gilmartin et al. (2011).

We evaluate past experience with translocation of Hawaiian monk seals by addressing four questions.

(Q1) Was the physical movement of the seal (i.e. capture, transport and release) successfully accomplished?

In the context of evaluating reintroductions, a class of translocations defined as "*intentional* movement of an organism into a part of its native range from which it has disappeared or become extirpated in historic times", Armstrong and Seddon (2007) emphasize the evaluation of dispersal and post-release survival. Hawaiian monk seal reintroductions have not been conducted, yet intended outcomes of translocations have included the subjects persisting in the general region where released. Therefore, we also evaluate the following:

(Q2) How long did seals remain at the release site prior to dispersal?

(Q3) Did translocated seals exhibit lower survival than comparable animals?

Finally, the stated goals of translocation actions were diverse and not necessarily limited to persistence at the release site. Thus, our final question:

(Q4) Were the goals of the translocation achieved?

2. Methods

Hawaiian monk seals occur throughout the Hawaiian Archipelago (Fig. 1), which consists of two regions: the main Hawaiian Islands (MHI, with eight primary high islands) and the Northwestern Hawaiian Islands (NWHI, made up of small coral islands, low-lying atolls, and steep basalt islands). Most monk seals reside in six primary NWHI subpopulations at Kure Atoll, Midway Atoll, Pearl and Hermes Reef, Lisianski Island, Laysan Island, and French Frigate Shoals. Necker and Nihoa Islands also host smaller numbers of seals (Ragen and Lavigne, 1999). A small but growing number of seals is distributed in the MHI (Baker et al., 2011). Finally, there have been rare and sporadic reports of seals visiting Johnston Atoll, south of the Hawaiian Archipelago, and some seals have been translocated to this atoll (Fig. 1).

We analyzed the translocations of 247 monk seals from 1984 to 2009. Seals of both sexes with ages ranging from less than a month to over 15 years were moved distances of just a few to more than 2200 km with a variety of intended aims. This diverse set of treatments was categorized based on age class of the translocated animals, region, and reason for the translocation action as summarized in Table 1. Captures were done using a hoop or stretcher net. Weaned pups were often transported in stretcher nets. Older animals were also moved short distances in nets in some cases. However, non-pups and all animals being transported for more than approximately 1 h, were transported in cages.

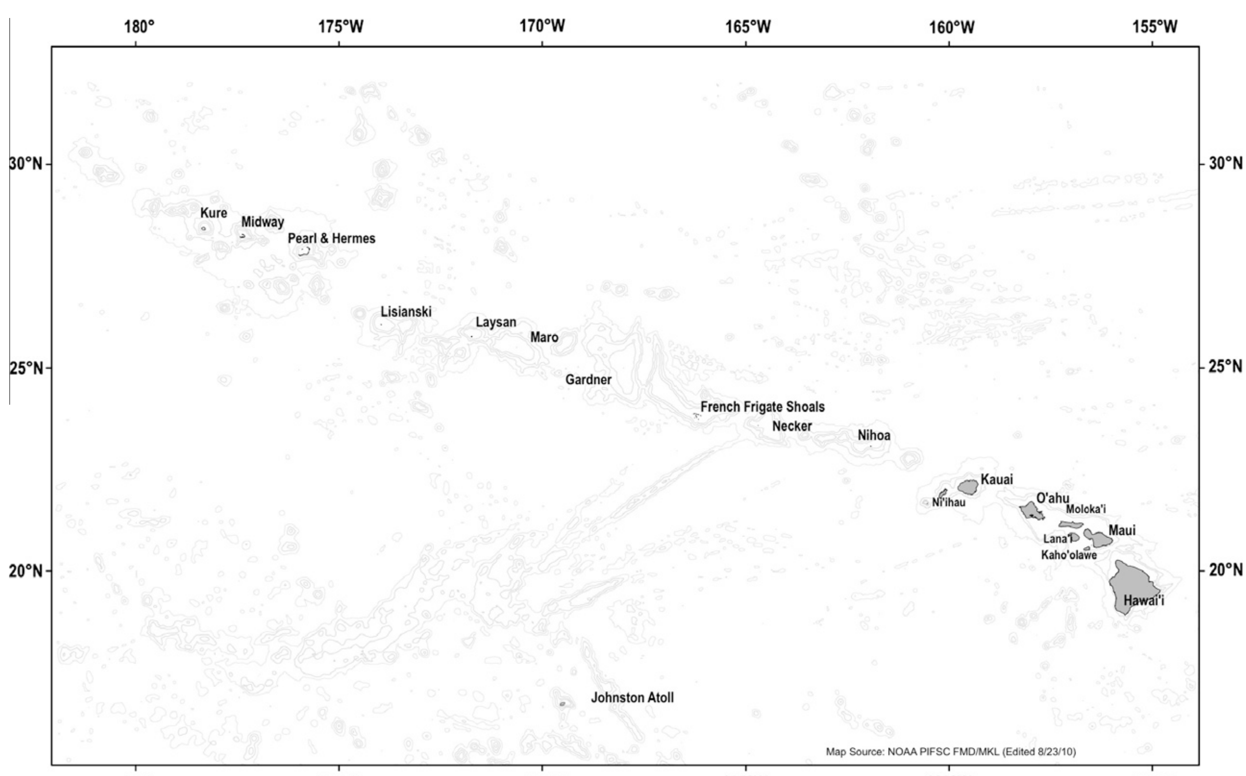

Fig. 1. The Hawaiian Archipelago and Johnston Atoll.

Table 1
Summary of Hawaiian monk seal translocations.

Age	Sex	From	To	Years	Reason	*N*
Nursing and weaned pup	Both	French Frigate Shoals	French Frigate Shoals	1994–2009	Shark predation risk, male aggression, foster	191
Weaned pup	Both	MHI	MHI and Kure Atoll	1991–2008	Human interaction, disease risk	13[a]
Weaned pup	Female	French Frigate Shoals	Kure Atoll	1990	Better foraging conditions	5
Nursing pup	Female	Laysan	Laysan	1999	Foster	1
Adult	Male	Laysan	Johnston	1984	Male aggression	10[b]
Adult	Male	Laysan	MHI	1994	Male aggression	22[c]
Adult	Male	French Frigate Shoals	Johnston	1998	Male aggression	2
Immature	Both	MHI	MHI/Nihoa/Johnston	2003–2009	Human interaction	3[d]
Total						247

[a] An additional 12 weaned pups were moved from French Frigate Shoals to Nihoa Island in 2008–2009. The results are still being assessed.
[b] One seal died prior to translocation, so that only nine were released.
[c] One seal died prior to translocation, so that only 21 were released.
[d] Includes RM34 (first moved as a subadult), RO42 (initially moved as a weaner to avoid freshwater stream, leptospirosis risk, then began interacting with people, and RW46 released after captive rearing).

2.1. Within-atoll translocations at French Frigate Shoals

Hawaiian monk seal mothers typically nurse their pups 5–7 weeks prior to weaning and leaving their pups on the natal island (Johanos et al., 1994). Since the late 1990s and continuing to present time, both pre-weaned and weaned monk seal pups have suffered abnormally high mortality as a result of predation by Galapagos sharks (*Carcharhinus galapagensis*, Gobush, 2010). While tiger sharks (*Galeocerdo cuvier*) are known to take monk seals of all ages post-weaning, Galapagos shark predation on pups has been observed only at French Frigate Shoals and, within that atoll, it has occurred most regularly at specific pupping islands, primarily Trig Island (Fig. 2). Galapagos shark predation appears to be the primary threat to young pups at French Frigate Shoals. In an effort to mitigate this early mortality, pups were captured as soon as possible after weaning and translocated in a small boat from islands with high predation risk to islands within French Frigate Shoals with lower observed risk, where they were released on land. Most of these translocations were accomplished within the course of a few hours, although some pups were held overnight prior to release. In addition to the weaned pups, three pre-weaned pups were translocated within the atoll to unite them with their own or a foster mother.

2.2. Pups in the main Hawaiian Islands

Because the MHI are rather sparsely populated by monk seals but host a large human population, mother seals sometimes give birth and nurse their pups in areas that are both isolated from conspecifics and frequently used by people. On weaning, the mother departs and leaves the pup at the natal site where it typically remains for many weeks (Henderson and Johanos, 1988). This combination of factors has sometimes led to seal pups interacting with, or becoming socialized to, humans, which often proves dangerous to both the seals and people. To preempt such situations, 13 weaned pups were moved from their natal sites to locations more

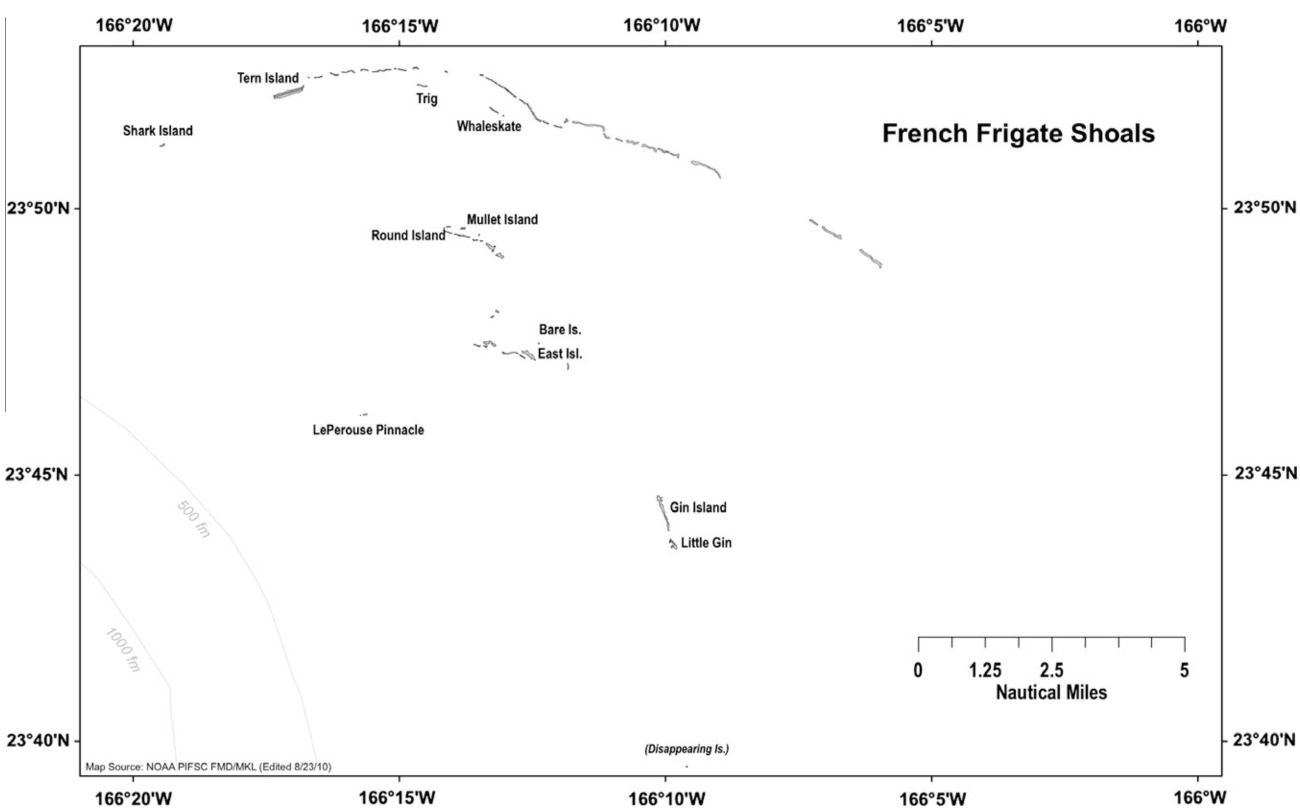

Fig. 2. Map of French Frigate Shoals with islets within the atoll indicated.

remote from humans and where conspecifics more regularly occurred. Pups were translocated either by automobile, ship or aircraft and were released on land.

2.3. Pups from French Frigate Shoals to Kure Atoll

In 1990, five healthy weaned female pups were taken from French Frigate Shoals and translocated aboard a research vessel directly to Kure Atoll, where their survival was anticipated to be higher. There, they experienced a "soft release", in that they were placed in shoreline pens for varying lengths of time and offered live reef fish. Between initial capture at French Frigate Shoals until release into the wild at Kure Atoll, these seals (and one Oahu-born pup translocated to Kure Atoll in 1991) spent 33–56 days in captivity (van Toorenburg et al., 1993).

2.4. Laysan Island pup translocation and fostering

In 1999, a nursing female monk seal lost her pup for unknown reasons 1 week after another pup had been prematurely weaned at 28 days of age. This latter pup had an axillary girth of only 89 cm, a size which made it unlikely to survive (Baker, 2008). Because monk seals frequently nurse pups other than their own (Boness et al., 1998), the prematurely weaned pup was captured, carried overland 4.5 km around Laysan Island and successfully fostered to the adult female who had lost her own pup.

2.5. Translocations to mitigate adult male aggression

Multiple male aggression is a phenomenon in which several adult male monk seals simultaneously attempt to mate with a single adult female (or more rarely, a younger seal of either sex). This frequently results in severe wounding or death of adult females (Hiruki et al., 1993a,b) and has most commonly occurred at Laysan Island. To mitigate this source of mortality and injury, 10 adult male seals were captured for translocation from Laysan Island to Johnston Atoll (approximately 1000 km east southeast of Laysan, Fig. 1) in 1984. In 1994, an additional 22 males were captured at Laysan Island for translocation to the MHI. A thorough analysis of the selective removals and subsequent reductions in male aggression are documented in Johanos et al. (2010). A distinct phenomenon, single-male aggression, occurs when individual adult male seals engage in aberrant focused aggression towards weaned pups, often drowning the victims or fatally wounding them. Two male seals, which had been observed engaging in this behavior at French Frigate Shoals in 1997 and 1998 were captured and taken to Johnston Atoll in 1998. All adult males were released from ships near shore.

2.6. Translocation of immature seals in the MHI

As noted above, 13 weaned pups were moved to prevent socialization with humans. Most of these involved recently weaned pups who were moved just once. However, four cases, each somewhat unique, involved multiple translocations during the first few years of life.

2.7. Data analysis

2.7.1. Northwestern and main Hawaiian Islands

A detailed demographic research program initiated at the six main NWHI subpopulations in the early 1980s provided the primary basis for evaluating translocations. Annual field camps (typically 2–5 months long) were conducted in the spring–summer period at all NWHI subpopulations involved in translocations. This program provides long-term individual identification of most seals through applied flipper tags, temporary pelage bleach marks and photographic identification using natural marks (Harting et al., 2004). Additionally, births and weanings were documented, pups were tagged and measured, and marked animals were resighted during regular beach surveys. The resulting data have been used to characterize Hawaiian monk seal vital rates, age structure, and abundance (Baker and Thompson, 2007; Harting et al., 2007; Johanos et al., 1994).

Monk seals were rarely observed in the MHI until the mid-1990s (Baker and Johanos, 2004). Limited demographic data have been collected in the MHI, which has historically hosted a relatively small portion of the total species abundance (Baker et al., 2011). In this study, the long-term mark-resight data from the NWHI and MHI were used both to provide information (*e.g.* age and gender) on translocated seals and to evaluate post-translocation movement and survival.

2.7.2. Time to dispersal

Our analysis of how long translocated seals stayed at their release sites prior to dispersal depended on the goals of the translocation as well as the spatial and temporal scale of available resighting data. For example, pups translocated among islets at French Frigate Shoals were monitored with periodic surveys of each islet occurring every few days to a week until each annual field season ended in late summer. Observation effort was inconsistent and sporadic during late summer through the following spring. Because these translocations were intended to keep pups on the islets where they were placed to avoid shark predation risk elsewhere, dispersal was defined as any observed movement to any islet other than where they were released. In many cases, gaps in observation effort meant that the actual timing of dispersal was imprecisely determined. Instead, the minimum time to dispersal was the statistic analyzed. This was calculated as the time interval between when a pup was translocated and its last sighting at the release location prior to being observed elsewhere. Minimum dispersal distance was estimated as the shortest over-water path between release site and the first observed post-dispersal location. We analyzed factors that influenced the minimum time to dispersal at French Frigate Shoals using a linear model with release island, the number of days between weaning and translocation, and the axillary girth at weaning (proxy for body condition, see Baker, 2008) as potential explanatory variables. Further, to establish whether translocated pups behaved differently from non-translocated pups, we used a linear model to analyze the minimum time between weaning and dispersal for translocated pups compared to pups born on the same islands where translocated animals were released.

Similarly, for pups translocated within the MHI, minimum time to dispersal was analyzed. However, the MHI are vastly larger than the tiny islets at French Frigate Shoals. Also, many of the MHI sightings came from volunteers or members of the public and the spatial resolution of observations was relatively low (typically a general beach name). Therefore, for MHI pups, we defined dispersal as movement away from the same beach or contiguous beach area.

Movements of translocated animals other than pups at French Frigate Shoals and the MHI were less well-documented. The pups taken to Kure Atoll were released near the end of the field season so that their movements after release were poorly known. The adult males taken to the MHI in 1994 were distributed among several sites. No focused resighting effort occurred after these males were released, so that only a few opportunistic sightings in the months post-release are available. Information for male seals taken to Johnston Atoll in 1984 is even more limited. Only a few opportunistic sightings, mostly of unidentified seals, were recorded by the US Fish and Wildlife staff and contractors on this otherwise uninhabited atoll. The two males taken to Johnston Atoll in 1998 were fitted with satellite-linked transmitters so that their movements in the short term were summarized. Finally, the three juveniles translocated within the MHI (including one eventually taken to Nihoa in the NWHI) were also tracked with satellite-linked transmitters for varying periods of time.

2.7.3. Survival

As with the dispersal analysis, the specific method used to analyze post-translocation survival varied with the different translocation treatments. Still, the general approach was to compare survival of translocated seals to comparable individuals occurring naturally at the release location. This allowed us to test whether there was a decrement in survival associated with translocation. Most translocations involved transporting all vulnerable seals from a site with a known or perceived threat (e.g. shark predation or likelihood of human interaction), so that it was impossible to evaluate the survival of translocated animals relative to comparable seals at the source site. In cases where like seals remained at the source site, such comparative analyses of survival were conducted.

For pups translocated within French Frigate Shoals, first-year survival of weaned pups that were moved to avoid shark predation was compared to that of pups born at the release islets in the same years. For at least approximately 4 weeks after weaning, pups tend to stay very close to where they were born (Henderson and Johanos, 1988). Because pups were usually not marked until weaning, we conservatively only assigned a birth island to those pups that had been tagged within 2 weeks of weaning. We limited the analysis to first-year survival, reasoning that any detrimental effects of pup translocation would be ephemeral. Following the approach of Baker (2008), because probability of resighting at French Frigate Shoals was very high (exceeding 0.90, Baker and Thompson, 2007), we used observed survival to at least age 1 year as a binary response variable and fitted logistic regressions to explore the influence of translocation, gender, year, and weaning girth on survival. Further, all observations of wounding (from shark bite or other causes) were recorded by field researchers and were scored according to established criteria as minor, moderate or severe. Thus, we included wounding severity in the survival model.

Similarly, first-year survival of weaned pups translocated in the MHI was compared to that of all other pups weaned in the MHI. Sample sizes for these groups were considerably smaller than at French Frigate Shoals, so that the influence of year, location, and gender could not be assessed. Likewise, survival of the five seals taken to Kure Atoll in 1990 was compared to those born at Kure in the same year.

Adult males translocated to the MHI in 1994 was the final group for which data were sufficient to quantitatively assess survival. As noted previously, resighting effort in the MHI was quite low compared to the NWHI, especially in the 1990s. To account for this low resight probability, an annual survival rate was estimated with Cormack-Jolly-Seber capture–recapture survival analysis in Program MARK (White and Burnham, 1999) with rMARK (Laake and Rexstad, 2007) as an interface. The results were compared to previously published estimates for adult survival of native-born MHI monk seals (Baker et al., 2011).

3. Results

3.1. Q1. Was the physical movement of the seal (i.e., capture, transport and release) successfully accomplished?

During 1984–2009, 259[1] monk seals were translocated, involving capture, transport, and release. Of the 259 translocated seals, three (1.2%) died during translocation procedures, including two adult males at Laysan Island and one weaned pup in the MHI. One of the adults died while being restrained, while the second adult and the pup died while being held in temporary captivity. Cause of death in all three cases could not be determined. Capture stress, pre-existing conditions or both may have been involved.

3.2. Q2. How long did seals remain at the release site prior to dispersal?

3.2.1. Pups within French Frigate Shoals

During 1994–2009, 191 pups were moved between islands within French Frigate Shoals. Of these, six pups were moved within the atoll twice for a total of 197 translocations. Of the 191 pups translocated, 76 dispersals (75 individuals, including one pup which was translocated twice and dispersed twice) away from the release islands were documented. The mean and median minimum times to dispersal were 42.8 d and 45 d, respectively ($s = 2.0$, $N = 76$). An additional 90 pups remained at their release islands at the end of the field season so that their time to dispersal was not known. Finally, dispersal after the remaining 31 other translocation events could not be assessed for various reasons.

We suspected that dispersal timing might be influenced by such factors as time since weaning, body condition and release site. We fitted a series of linear models with minimum dispersal time as the response variable and days post-weaning when translocated, girth at weaning, and release island as predictors. The sample of 76 observed dispersals was reduced to 72 for this analysis to avoid pseudo-replication (animals moved twice), highly uncertain dispersal timing and islands where only a single pup was released.

Relative support for a saturated model (all predictors included), a null model, and a series of reduced models with individual independent variables was evaluated with small sample Akaike's Information Criterion (AIC_c, Anderson et al., 2000). A model with only release island had the most support relative to the null model ($\Delta AIC_c = 6.8$). Including either weaning girth or time since weaning reduced model support. The minimum time to dispersal from the three release locations were: Gin Islands (mean = 39.6d, $s = 2.5$d, $N = 36$), Tern Island (mean = 44.2d, $s = 2.9$d, $N = 33$), and East Island (mean = 72d, $s = 15.3$d, $N = 3$).

Comparing the dispersal behavior of pups born on the same islands where translocated pups were released differed from the above analysis in a subtle way. Previously, we analyzed the minimum time from translocation to dispersal, whereas in the present analysis untranslocated pups were by definition not released. Thus, we instead compared the minimum time from *weaning* to dispersal of both groups, exploring the effects of translocation, gender, and location (island). As in the above analysis, a model including location only had the lowest AIC_c ($\Delta AIC_c = 11.1$ compared to the null model). A model including both location and translocation increased AIC_c by 4.6, supporting the conclusion that translocating weaned pups did not alter their subsequent dispersal.

3.2.2. Other translocated pups

For pups translocated other than within French Frigate Shoals, both sample sizes and available resighting information were limited. As a result, post-translocation dispersal information is largely descriptive. Of the 12 MHI pups translocated, 11 were moved away from their weaning site to locations on their natal island primarily to preempt human interactions. One was moved from Oahu to Kure Atoll for the same reason. A minimum or a range of time to dispersal was obtained for 8 of the 11 pups translocated within the MHI. Of those observed to disperse, five were seen only at the release locale for at least 48 days post-release. Another's dispersal timing was highly uncertain (3–86 days) because of a lack of observation effort. Two pups did not remain at their release

[1] In addition to the 247 seals reviewed in this paper (Table 1), 12 weaned pups were successfully moved from French Frigate Shoals to Nihoa Island in 2008–9, bringing the total translocated individuals to 259.

sights for long. One of these had been translocated more than 2.5 months post-weaning, by which time pups are mobile and feeding independently. The other was translocated only 2 days post-weaning, yet remained at the release location only 4–6 days. She was subsequently recaptured and moved again but remained at the second release site only 2 days. This seal became habituated to humans and was translocated several more times in the next few years. The first observed minimum dispersal distances (from release site to first other location documented) for these 8 pups ranged from 2 to 10 km. The six pups translocated to Kure Atoll (Table 1) were not monitored long enough in the release years to allow proper assessment of dispersal.

3.2.3. Adult males

Twenty-one adult males translocated from Laysan Island in 1994 were released offshore of the MHI (Hawaii – 6, Maui – 4, Molokai – 5, Kahoolawe – 2, Oahu – 2, and Kauai – 2). Because there was no dedicated post-release monitoring effort, opportunistic sightings were available only for seven of these adults after release in 1994. All seven of the adult males resighted during their release year had dispersed varying distances. Due to scant resighting effort, only the maximum time to dispersal could be determined (time from release until the subsequent 1994 resighting), which ranged from 4 to 143 d (median 12 d). The minimum dispersal distance from release site to the location of the subsequent sighting ranged from 19 to 304 km (median 35 km). Notwithstanding the limited data available, it is clear that these adult seals were highly mobile. Three of the seven traveled between islands by the time they were first resighted.

On a longer time scale, some of these translocated males have been resighted for over 15 years after being translocated, with individuals resighted in as many as 9 particular years. Among the 17 seals seen for at least 1 year after translocation, 15 were documented on either two (five seals), 3 (five seals), 4 (four seals), or 6 (one seal) different islands. Despite this level of mobility, only one adult male from Laysan was observed to make two excursions back to the NWHI (he was observed at Nihoa Island in 1996 and 2006), each time returning to the MHI.

3.3. Q3. Did translocated seals exhibit lower survival than comparable animals?

3.3.1. Pups within French Frigate Shoals

To compare survival of weaned pups translocated within French Frigate Shoals to that of non-translocated pups, we controlled for several factors and covariates expected to influence survival. Previous studies have indicated that at French Frigate Shoals, survival from weaning to age 1 year varies with year, weaning girth, and sex (Baker and Thompson, 2007; Baker, 2008). Further, we anticipated that survival might vary among islets within the atoll. We, therefore, limited our survival analysis data set to pups weaned at the release islands in the years when translocations occurred, and included only seals with weaning girth measurements. The influence of the presence of wounds (classified as minor, moderate or severe) on survival was also evaluated. The total sample size for this analysis was 291 pups (161 translocated and 130 non-translocated) born in 1997, 2001–2008.

Generalized linear model results are presented in Table 2. Initially, a saturated model was fitted, and the least influential predictors (based on estimated coefficients and their standard errors) were sequentially removed. As expected, based on previous studies, girth and year strongly influenced survival. A model including sex had essentially the same support as one with girth and year ($\Delta AIC_c = 0.43$). Whether or not pups had been translocated likewise did not improve model fit ($\Delta AIC_c = 2.24$), and overall 45% of translocated pups survived versus 43% of non-translocated pups. Unexpectedly, accounting for presence of wounds also did not improve the model, whether included as a factor or covariate (ordered in increasing severity). Overall, pups without wounds (44%) and with wounds (mild – 43%, moderate – 45%, severe – 36%) showed similar survival rates. Finally, island (Tern, East or Gins) did not influence survival outcomes.

3.3.2. Other translocated pups

Of the 12 weaned MHI pups translocated between 1991 and 2008 (excluding 1 which died in captivity), 8 (67%) survived at least 1 year after translocation. Survival from weaning to age 1 year of translocated and non-translocated seals since 1988 was analyzed using logistic regression. While 79% of non-translocated MHI pups lived 1 year or more ($n = 84$), compared to 67% for 12 translocated pups, this difference was not statistically significant (logistic regression, $p = 0.36$). The bodies of two translocated pups were recovered; both had been released on an offshore State of Hawaii bird preserve (Rabbit Island) with restricted human access. One had drowned in a lay gillnet approximately 2 km away. Cause of death of the latter pup was undetermined, but the lack of any alternative post-mortem explanation coupled with reports of illegal gillnet fishing in the same area in preceding days suggested that drowning in a gillnet was likely.

Of the five weaned pups moved from FFS to Kure in 1990, four (80%) survived at least their first year. Three pups were born and weaned at Kure in 1990, of which 2 (67%) survived their first year (no significant difference, logistic regression, $p = 0.68$). In comparison, 30 female pups were weaned and remained at French Frigate Shoals in 1990. Of these, 18 (60%) survived to at least age 1 year. That survival rate was also not significantly different from the translocated pups (logistic regression, $p = 0.41$). However, the difference in survival outcomes of the translocated seals and those left at French Frigate Shoals appeared to be greater when measured over a longer time. Two of the five (40%) translocated animals lived to reproductive age and beyond (11 years and at least 19 years). In contrast, reproductive age (15 and at least 19 years) was attained by only 2 of 30 (7%) of those remaining at French Frigate Shoals (logistic regression, $p = 0.06$).

3.3.3. Adult males

Translocated adult males' survival was estimated from 1994 to 2009 sighting data using a Cormack–Jolly–Seber capture–recapture model with a single survival parameter and time variant recapture probabilities. Because they were from 5 to at least 15 years old when released in 1994, the males were all in the age range when constant "mature" survival rates are operative (Baker and Thompson, 2007). Therefore, we did not include age variation in the survival model. Also, because the sample was small and adult survival tends to be less variable than it is for immature seals, we fitted a constant survival parameter for all years. Because pre-

Table 2
Generalized linear modeling results comparing survival from weaning to age 1 year at French Frigate Shoals. Factors and covariates examined included weaning girth, birth year, sex, island, presence of wounds, and whether or not seals were translocated after weaning. Models are ranked according to AIC.

Model	df	AIC	ΔAIC
Girth + year	10	338.923	
Girth + year + sex	11	339.173	0.250
Girth + year + sex + translocation	12	340.798	1.875
Girth + year + sex + translocation + wound (covariate)	13	342.112	3.189
Girth + year + sex + translocation + wound (factor)	15	345.995	7.072
Girth + year + sex + translocation + wound (factor) + island	17	349.676	10.753
Null	1	400.694	61.771

vious MHI survival analysis (Baker et al., 2010) revealed that resight probabilities increased starting in 2001, we fitted varying capture probability by grouped years (1995–2000 and 2001–2009). Estimated annual survival for the translocated males was 92.3% (95% CI 87.4–95.5%), which is comparable to that seen for native-born adults in the MHI (Baker et al. 2010), 94.3% (95% CI 87.8–97.4%). Similarly, previously published annual survival rates of adult seals (there were no sex differences) remaining at Laysan Island after 1994 ranged from 90.4% to 97.4% (Baker and Thompson, 2007). The translocated seals' survival estimate is likely biased slightly low because of tag loss. For several years, little resighting effort occurred so that lost tags would not have been replaced, and little or no photographic identification effort also occurred. In contrast, native born seals were followed more closely and photographic identification effort was greater. Estimated capture probability of the translocated seals was only 18.5% (95% CI 11.8–27.7%) from 1995 to 2000. Thereafter, capture probability increased to 66.3% (95% CI 54.0–76.7%). Two seals resighted in the MHI are known to have been translocated from Laysan based on the color of their broken and undreadable tag remnants. However, because they cannot be identified, their survival is not reflected in the above analysis.

In contrast to the adult males released in the MHI, those taken to Johnston Atoll did not apparently fare as well. Of nine adult males taken from Laysan Island to Johnston Atoll in 1984, a maximum of three were opportunistically seen by the US Fish and Wildlife Service staff in 1985. The individuals were not identified so that there could have been just one, two or three seals seen on three occasions. In 1986, one seal was seen at Johnston Atoll and positively identified as a Laysan translocatee. After 1986, none of the males translocated in 1984 was positively identified, though scattered unidentified monk seal sightings have continued to occur. These may have been one or more of the males from Laysan. Alternatively, they may have been natural migrants from Hawaii, as monk seals are known to occasionally occur at Johnston Atoll (Schreiber and Kridler, 1969).

The two males translocated to Johnston Atoll from French Frigate Shoals and released on 8 June 1998 were fitted with satellite-linked telemetry devices (Stewart, unpublished report). Their movements were documented until 14 and 20 July, respectively, when the devices either failed, detached or the seals died. One of the two males traveled as far as 250 km to the south and 500 km to the northeast of Johnston Atoll before his device ceased transmission. The other seal spent more time near the atoll but then also began moving north towards Hawaii until contact was lost. Neither seal was subsequently seen.

3.3.4. Translocation to mitigate human–seal interactions

Four cases involved translocations intended to end human–seal interactions, while allowing the seals to remain wild in the MHI. Three involved pups that weaned in areas where there was little or no opportunity to socialize with other seals. Eventually, all three seals began socializing or taking food from people. The fourth case involved an abandoned pup that had been reared in captivity for approximately 7 months prior to release at a location frequented by seals but with few people. Undoubtedly accustomed to humans from his captive experience, the seal sought out and began interacting with people. Primarily based on persistent concerns for public safety, each seal was translocated from two to five times. Initially, release sites were isolated beaches on the natal island, but progressed to other islands where there were more seals and fewer people.

Ultimately, only one case may have achieved the dual objectives of ending interactions while allowing the seal to live in the MHI. A pup was moved twice, the second time to Niihau Island, after which reports of human interaction ceased. Three other seals, ranging up to 2 years of age, all persisted in seeking human interactions, often traveling to find people from 1 to 6 days after being translocated to remote areas. They were ultimately removed from the MHI. One was taken to Johnston Atoll and not subsequently resighted. Another was taken to Nihoa Island (NWHI) where, according to satellite telemetry, it persisted for at least a month, making normal foraging excursions to sea and returning to the island. This seal may well still be alive. Finally, the captive-reared seal was returned to captivity when it was discovered that eye opacities severely impaired his vision.

4. Discussion

4.1. Q1. Was the physical movement of the seal (i.e. capture, transport and release) successfully accomplished?

The experience to date with translocation of Hawaiian monk seals demonstrates that there is little risk to the seals associated with the mechanics of capture, transport, and release. A wide variety of transportation methods have been employed, including carrying seals on foot, transporting in small boats, large ships and aboard aircraft. Monk seals are clearly robust animals and can readily withstand temporary handling and captivity. We believe the rarity of translocation-related mortality has also resulted from strict adherence to cautious handling and transport protocols. Necropsies or observed circumstances did not reveal the cause of three mortalities; thus, it is not possible to determine what went wrong in those cases.

4.2. Q2. How long did seals remain at the release site prior to dispersal?

The primary conclusion from analysis of post-translocation dispersal is that weaned Hawaiian monk seal pups reliably remained where they were released typically for 7 weeks or more. This pattern is consistent with the behavior of non-translocated pups compared in this study and previous observations (Henderson and Johanos, 1988). Weaned pups, then, are at an ideal age for translocations because their sedentary behavior affords a conveniently high measure of predictability in the animals' post-release range. This also facilitates post-release monitoring. Translocated pups showed no proclivity to return to their natal site after translocation.

In contrast, older seals showed a distinct tendency to roam wider and sooner after being translocated. This is almost certainly a result of older animals being accustomed to foraging and traveling at sea, whereas weaned pups have little such experience. However, the observation that older seals dispersed more rapidly could also have been related to the fact that many of them were released in nearshore waters rather than on land. Unfortunately, in this retrospective study, age class and release type (land or sea) were confounded. Nevertheless, we expect that experienced foragers would more likely disperse readily even if released on shore. It would be helpful to know at what age the tendency emerges to disperse soon after release. We posit that this likely occurs concomitantly with the development of foraging skills in the first year of life. However, because nearly all the translocations to date have involved either recently weaned pups or adults, the available data cannot resolve this question.

While the movements of translocated adult seals were far less constrained than pups, most tended to stay in the general region where they were released. For example, of the 21 adult males taken from Laysan Island to the MHI, none was ever observed back at Laysan Island, and only one traveled back to the NWHI (to Nihoa Island, and then only temporarily). In contrast, the two males fitted with satellite transmitters when taken to Johnston Atoll in 1998 apparently attempted to disperse from their release site after a few weeks. The lack of other seals at Johnston Atoll might have influenced their decision to leave.

4.3. Q3. Did translocated seals exhibit lower survival than comparable animals?

When post-release translocated seals could be compared to seals native to the release site, there was no statistically significant difference in survival. While the sample sizes for some of these groups were admittedly small, we note that in most cases the survival rate point estimates were very similar for translocated versus non-translocated seals. The 67% first year survival estimate for a relatively small number of pups ($N = 12$) translocated within the MHI was somewhat lower than for MHI natives (79%) and, until more cases accrue, we cannot rule out that this was a real difference in the underlying survival rates.

In addition to evaluating survival rates, it is also illustrative to glean lessons from known or suspected mortalities. The releases at Johnston Atoll are noteworthy in this regard. While post-release monitoring was admittedly suboptimal, especially after the 1984 translocations, it appears that monk seals released at Johnston Atoll did not persist there for long. The disappearance of the two adults and a subadult taken to Johnston Atoll in 1998 and 2003, respectively, further reinforces this conclusion. It is unclear why monk seals taken to Johnston Atoll failed to thrive and persist there.

4.4. Q4. Were the goals of the translocations achieved?

4.4.1. Mitigation of Galapagos shark predation on weaned pups

Moving weaned pups from islets with high incidence of shark predation at French Frigate Shoals was likely successful in reducing injury and mortality from this cause. While the post-weaning to first year survival of these translocated pups was not particularly high (45%), it was essentially equal to that of pups weaned at the release islets (43%). It is not possible to unequivocally conclude that these pups fared better than they would have if left in place, because in years when shark predation was apparent and translocations occurred, no weaned pups were left on the high risk islands. Thus, there were no controls to which the translocation treatments could be compared. Nevertheless, continued *pre-weaned* pup mortality attributed to Galapagos shark predation at the high-risk islands strongly suggests that the removals reduced risk. In addition to ongoing weaned pup translocations, attempts to deter or remove predatory sharks are also underway (Gobush, 2010).

4.4.2. Improving foraging conditions for weaned pups

Seventeen weaned pups were translocated from French Frigate Shoals expressly because foraging conditions, and thus prospects for juvenile survival were judged to be poor at that site. Twelve of these were translocated to Nihoa Island in 2008–2009, and their success rate cannot yet be evaluated. However, while the sample size available for evaluation is very small (five translocated to Kure Atoll from French Frigate Shoals in 1990), the rather large difference in survival to reproductive age (40% of translocated versus 7% of those left at French Frigate Shoals) suggests that this action was successful.

4.4.3. Mitigating male aggression

Whereas all other translocations were conducted to benefit the animals being moved, adult male translocations were conducted to benefit animals remaining at the source subpopulation. In this respect, adult male removals have been very successful. Johanos et al. (2010) present a thorough analysis of the effect of removing males from Laysan Island on the incidence of wounding and mortality of female seals. Adult female mortality, as a result of male aggression, sharply dropped from an average of 4.1% per year to only 0.3% per year after males were removed in 1994.

Evaluating the success of the translocations of two adult males in 1998 to mitigate single-male aggression is somewhat more complicated as cause of death or disappearance is not always clear. Annual reports of field research use a conservative set of criteria to ascribe causes of injuries, death, and probable deaths (Johanos and Baker, 2000, 2001, 2002, 2004; Johanos and Ragen, 1999a,b). Fig. 3 shows the number of pups at French Frigate Shoals that were documented victims of male aggression from 1996 to 2001. There was a peak in such occurrences in 1996–1997, and two males involved were identified during the 1997 season. After this activity was observed again in 1998, these two males were promptly removed. While there were several incidents again in 1999, the rate at which pups were lost was notably lower after the removals, indicating that the translocations achieved their desired effect.

4.4.4. Mitigating human interactions

Translocations that were conducted to mitigate human–seal interactions were either preventative (moving weaned pups from areas with high human use) or interventions (moving juvenile seals already known to interact with people). The former method appears to have achieved some success. Of the 11 weaned pups moved within the MHI primarily to preclude interactions, only two subsequently became problem seals socialized to humans. It is not possible to truly quantify the success of these translocations because "control" animals were not left in places where human and fishery interactions seemed highly likely. That is, managing a perceived threat to these members of an endangered species took precedence over conducting a classical experimental design.

In contrast to preventative translocations of weaned pups, which appear to have achieved some success, intervening to mitigate already established human–seal interactions typically failed. Translocations within the MHI provided, at best, short-lived diminishment of interactions, with the possible exception of one seal. The remaining three cases involved multiple translocations of each seal, finally resulting in removal from the MHI population. In this way, the seals were ultimately prevented from continued human interaction, but at the high cost of removal from their population.

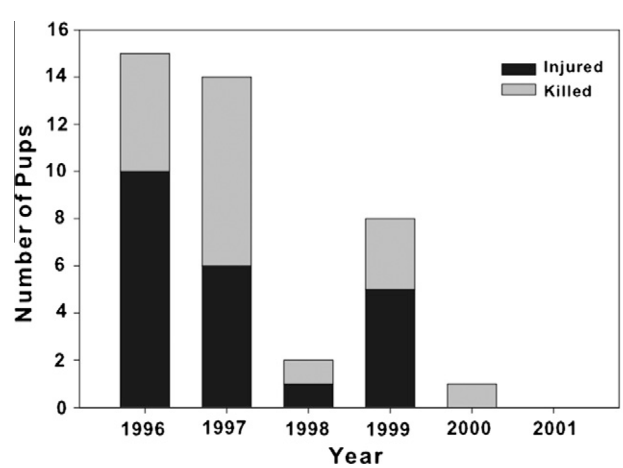

Fig. 3. Number of Hawaiian monk seal pups injured and killed at French Frigate Shoals as a result of single-male aggression during 1996–2001. The killed category includes both confirmed deaths and pups that disappeared after sustaining injuries during an encounter with an aggressive male, and are last seen in a severely compromised condition. Two adult males that had been identified as aggressors were removed partway through the 1998 field season.

It seems clear that preventative translocations conducted soon after weaning hold the most promise and that simply translocating seals already accustomed to interacting with people is unlikely to succeed. This is entirely consistent with previous reviews that concluded translocations aimed at resolving human–wildlife conflict tend to be unsuccessful (Fischer and Lindenmayer, 2000; Linnell et al., 1997).

5. Conclusion

Hawaiian monk seals have been translocated for a variety of conservation and management purposes. Analysis of these efforts led to the following conclusions:

- Risk of mortality during capture and transport is quite low.
- Post-release survival of translocated seals was no different from seals native to the release locations.
- Weaned pups appear most amenable to translocation as they tend to remain near their release sites for an extended period prior to dispersing.
- Older seals disperse sooner and further from release sites in comparison to weaned pups.
- In most cases, the stated goals of translocations were achieved, with the notable exception of most efforts to mitigate already established human–seal interactions.
- Translocation remains a viable tool for future Hawaiian monk seal conservation efforts.

Acknowledgements

The data analyzed in this paper reflect the efforts of scores of workers: field researchers, veterinarians, technicians and volunteers. Transport for people and seals was provided by the US Coast Guard, as well as the officers and crews of the NOAA Ships *Townsend Cromwell* and *Oscar Elton Sette*. Albert Harting provided a valuable review of this manuscript.

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