DRAFT
Programmatic Environmental Impact Statement
Appendices A-L

Hawaiian Monk Seal Recovery Actions

August 2011

Prepared for:

NATIONAL OCEANIC AND ATMOSPHERIC ADMINISTRATION
U.S. DEPARTMENT OF COMMERCE

Appendix E
Proposed Translocation Plan

This page intentionally left blank.

Two-Stage Translocation: A Proposal for Enhancement of the Endangered Hawaiian Monk Seal[1]

Pacific Islands Fisheries Science Center
National Marine Fisheries Service, NOAA
1601 Kapiolani Blvd., Suite 1110
Honolulu, Hawaii 96814-4733, USA

---

[1] An earlier version of this document was prepared for a Society for Conservation Biology (SCB) blue ribbon panel review of the science supporting two-stage translocation. Some of the comments and suggestions arising from the SCB review (completed 7 February 2011) have been incorporated into the current version of this document. Other suggestions, such as providing a wider range of metrics for evaluating two-stage translocation benefits, were incorporated directly into Chapter 4 of the PEIS.

Context and Scope

The National Marine Fisheries Service (NMFS) is proposing a novel strategy for boosting juvenile Hawaiian monk seal survival. The proposal involves temporarily translocating weaned female pups from subpopulations with relatively low juvenile survival to alternate sites where juvenile survival is much higher, then returning them several years later. The objective is to reduce early mortality of these individuals, which is exceptionally high in the first two years of life and is thought to be the primary factor limiting population recovery. The proposed translocations would ideally preserve sufficient reproductive potential within monk seal subpopulations maintaining the capability for more rapid growth should conditions currently constraining survival eventually relax. Given recent trends for this species (4% annual decline in abundance), this logic is admittedly optimistic, but some improvement in natural survival will surely be required if the species is to avoid extinction.

Current survival rates suggest the most favorable option (purely in terms of demography) would involve temporarily moving seals from the remote Northwestern Hawaiian Islands (NWHI) to the main Hawaiian Islands (MHI), an initiative that would undoubtedly involve some controversy related to socio-economic issues. A draft Programmatic Environmental Impact Statement (PEIS) to support this proposal as well as other recovery actions will be completed by Spring 2011.

As described below, the proposed translocation program is but one of several actions, currently underway or proposed, to conserve the Hawaiian monk seal. All of these actions have been, or will soon be, subject to scrutiny for NEPA clearance, MMPA/ESA permitting, IACUC approval, and Recovery Team and Marine Mammal Commission review. Most of these activities have a long history of positive application to monk seals or demonstrated precedent in other wildlife management or conservation programs.

In contrast, the proposed translocation program is novel in many respects and deserves special consideration. Social and economic concerns associated with translocations will be thoroughly analyzed and addressed during the PEIS and permitting processes. However, the PIFSC has further commissioned this special Society for Conservation Biology (SCB) review of the science of its proposed translocation strategy. The PIFSC recognizes that the proposed two-stage translocation program has unique features in terms of its design, execution and underlying scientific principles when compared to 'traditional' translocation or reintroduction programs. As such, the SCB review is intended to evaluate the scientific support for the proposed strategy. While recognizing that the translocation program would occur as one element of a more comprehensive research and enhancement program, the scope of this review is relatively narrowly focused on translocation science.

Background

Distribution and Population Status

The Hawaiian monk seal ranges throughout the entire Hawaiian Archipelago with rare occurrences recorded at Johnston Atoll, approximately 800 km south of Hawaii (Figure 1).

The species is structured in a metapopulation consisting of eight NWHI subpopulations, which together comprise roughly 85% of total abundance; the remainder is distributed amongst the MHI. The monk seal subpopulations display varying degrees of demographic independence but are linked through regional environmental correlation as well as migration (Baker *et al.* 2007, Baker and Thompson 2007, Schultz *et al.,* in press). A proxy for movement rates among subpopulations (the proportion of tagged seals seen at other than their natal site during their lifetime) ranges from 4% to 18% depending upon the site (Schultz *et al.,* in press). Effective migration has apparently been sufficient to preclude any discernable genetic population structure, such that the species is comprised of a single panmictic population (Schultz *et al.* 2009, Schultz *et al.,* in press).

Total Hawaiian monk seal abundance is approximately 1,100 individuals with subpopulations ranging from roughly 50 to 200 seals each. The overall population abundance is falling by an estimated 4% per year. The six most-studied subpopulations in the NWHI (French Frigate Shoals, Laysan Island, Lisianski Island, Pearl and Hermes Reef, Midway Atoll and Kure Atoll) are currently declining with estimated intrinsic rates of increase (λ) ranging from 0.89 to 0.96 (Baker *et al.* in press). Necker and Nihoa Islands appear to be stable or increasing, however the demographics at these two sites are relatively poorly characterized due to their difficult access and historically relatively small contribution to total abundance. In contrast, the MHI population is increasing with an estimated λ of 1.07.

Poor post-weaning juvenile survival is the primary driver of the population decline in the NWHI and, conversely, favorable survival in the MHI contributes to that region's robust growth. Recent survival to age curves (l_x) demonstrate the divergent survival regimes operating between the NWHI and MHI (Figure 2). Chronic poor juvenile survival for time periods ranging from 10-20 years in the NWHI have resulted in degraded age structures exhibiting an over-representation of newborns and older seals, with few juveniles and young adults.

Age-specific fecundity (m_x) has been rather well characterized for three NWHI subpopulations (Harting *et al.* 2007, Figure 3). The curves vary among these sites and tend to be somewhat lower than for other pinnipeds. There is some evidence that MHI seals enjoy earlier maturation and higher reproductive rates, at least among the younger adults (Baker *et al.* in press). Nevertheless, survival rates are the primary factor determining population status and trends at present.

Causes of population decline

The 2007 Recovery Plan for the Hawaiian Monk Seal (NMFS 2007) identified three "crucial" threats to the species:

- **Food limitation,** the primary cause of low juvenile survival.
- **Entanglement** in marine debris, which affects all ages and sexes, but disproportionately involves juvenile seals.

- **Shark predation,** particularly Galapagos shark predation on pups at French Frigate Shoals.

Another set of second tier "serious" threats include infectious disease, terrestrial habitat loss in the NWHI (especially due to sea level rise), intra-specific male aggression, and human interactions especially in the MHI (disturbance, fishery interactions, etc.).

While certain of these threats can have important sporadic or localized impacts (*e.g.*, male aggression) or have *potential* for widespread, devastating impacts (epidemic disease), it is generally agreed that the primary cause of the current decline is food limitation leading to unsustainably high levels of juvenile mortality (Antonelis *et al.* 2006, Baker 2008). Insufficient availability of prey for young seals may be mediated through poor or variable overall system productivity, competition with other top predators (Baker *et al.* 2007, Polovina 2008, Baker and Johanos 2004, Parrish *et al.* 2008), or both. In any case, because the diagnosis indicates a deficiency in the ecosystem that is leading to the demise of young monk seals, there are no simple or certain remedies. Thus, a set of novel tools, including a new translocation approach, is being proposed. Below we describe past, ongoing and future planned interventions to provide some context for the translocation proposal that is the focus of this review.

Past and current enhancement activities

Due to steep declines in abundance following surveys in the late 1950s, the Hawaiian monk seal was listed as endangered under the United States Endangered Species Act (ESA) in 1976. Efforts to monitor the species and foster its recovery began in the early 1980s, led by the NMFS as prescribed by the ESA. Monk seal population assessment has focused on determining abundance, age and sex structures, survival rates, reproductive rates, and causes of injury and mortality. The Hawaiian monk seal thus has the distinction of being the subject of a long-term and thorough demographic study on a par with that undertaken for any large, free-ranging mammal in the world. Relying on the rich data set accumulated from over two decades of research, a suite of demographic parameter estimates has been updated annually for six NWHI subpopulations, with less data available from Necker and Nihoa Islands, and more recently, data from the MHI. Summarized demographic data are typically available for review within a few months after annual field seasons have ended. Further, robust investigations of foraging behavior and monk seal health and disease are ongoing. This rich, two-decade plus research data set is essential for evaluating past recovery efforts and designing future measures. A primary focus of the research program has naturally been to discover and, when possible, mitigate natural and anthropogenic threats to the species.

Future proposed interventions

Despite the many past efforts and those ongoing, the monk seal's status continues to erode. The efforts outlined above have no doubt slowed the species' decline, but it is broadly agreed that more must be done to save the species from further deterioration and ultimately, extinction. Because the primary driver of decline is low juvenile survival, successful interventions must be directed toward the early life stages: pups and juveniles. However, due to the condition of age structures and vital rates in the NWHI as described above, the number of pups available for intervention is projected to rapidly decline (Figure 4). This realization heightens the sense of urgency to begin interventions before the opportunity to effect meaningful improvement expires.

Many past and current efforts will be continued into the foreseeable future as these measures have clear and direct benefits. These include, but are not limited to, disentangling seals caught in marine debris, removing fishing hooks from seals, large-scale removal of potentially entangling marine debris from beaches and reefs, and mitigating Galapagos shark predation and intra-specific male aggression when needed. Some translocations, already authorized, will continue. For example, within-atoll translocation of weaned pups from high shark predation islets to historically safer islets at French Frigate Shoals is a successful tool for mitigating post-weaning Galapagos shark predation. In the MHI, pups that wean in high human-use areas isolated from other seals may also be translocated to more favorable sites when deemed beneficial. Finally, translocation of adult males is one option authorized for mitigating male seal aggression.

The robust Hawaiian monk seal research effort will continue and expand in the future. This program is focused on four broad areas: population monitoring, foraging ecology, health studies and survival enhancement research. The full details of the research program are beyond the scope of this document, but it is important to recognize that each element of research inquiry is integrated into the goal of species' conservation. Investigations serve to identify threats, characterize underlying factors that influence survival and reproduction, design interventions, and evaluate the success of conservation measures.

Coupled with the research program is an expanding management effort, primarily focused on the MHI. The management program, led by the NMFS Pacific Islands Regional Office entails stranding response, public outreach and education, and legal/regulatory issues.

Another anticipated expansion is in the area of captive care of monk seals. In collaboration with the Marine Mammal Center in Sausalito, NMFS is pursuing expanded capacity for captive care facilities. Care would be provided to seals brought into temporary captivity under the authority of the NMFS Marine Mammal Health and Stranding Response Program. Captive care efforts would be limited to animals deemed in need of medical intervention.

In addition to the foregoing measures, a set of new research and enhancement tools is under consideration to promote recovery of the Hawaiian monk seal. These include:

- Two-stage translocation
- De-worming
- Vaccination research
- Behavioral modification

The proposed two-stage translocation program is the subject of this paper and SCB review, however the other three initiatives will be described briefly.

De-worming is currently being investigated as a means for improving free-ranging juvenile seal survival by temporarily reducing gastrointestinal parasite burden. If this approach is determined to be feasible and effective, it may be used as an enhancement tool.

Vaccination research is meant to address potential disease (*e.g.*, morbilliviruses and West Nile Virus) outbreaks that could devastate Hawaiian monk seals. If the safety and efficacy of specific vaccines are established, then these could be used either prophylactically or as a response tool to contain an outbreak.

Behavioral modification research addresses a range of measures primarily intended to prevent or mitigate human-seal interactions. Occasionally seals become socialized to humans in the MHI and because of the dangerous nature of their interactions with people, these seals have typically been translocated from the MHI or brought into permanent captivity. Seals also interact with fishers, sometimes to the detriment of the former (hooking, entanglement, shooting) and the latter (loss of catch, damaged gear). Tools to prevent or alter such behavior will be in greater demand as the MHI monk seal population continues to grow. As the tools and protocols for effective behavior modification are refined, they will become an integral component of monk seal management in the MHI.

Two-stage Translocation

Basic concepts

According to the "IUCN Guidelines for Reintroduction", translocation is defined as *"deliberate and mediated movement of wild individuals or populations from one part of their range to another"* (IUCN 1998). Translocation has proven to be one of several useful tools in the Hawaiian monk seal conservation effort (Baker *et al.* in review). The NMFS is proposing a novel approach to further apply translocation to enhance the Hawaiian monk seal population. Translocating individuals would have one or more of the following objectives:

1) Increase individual fitness (especially survival).
2) Improve the species status (*e.g.*, abundance, population reproductive value).
3) Maintain meta-population structure for long-term resiliency.

The fundamental concept underlying application of translocation is to address mismatches between local environmental conditions and distribution of seals among subpopulations. For example, some pups wean at subpopulations where they experience high mortality, apparently largely due to insufficient prey resources. Thus, many of these neonates perish, whereas, because of spatial variability among sites, they might have survived elsewhere. This would be tolerable under different conditions. That is, if the monk seal population were large and if mean environmental conditions were more favorable (although still punctuated with periods of unfavorable conditions), the meta-population might achieve a sort of dynamic stability across the entire range. The current situation, however, is not sustainable because the number of monk seals is perilously low and steadily declining. Further, adverse conditions have largely prevailed for a decade or more, and natural dispersal occurs at far too slow a rate to effect a more optimal distribution.

Translocation, then, is a tool that could mitigate population decline by accelerating dispersal of young animals from areas of low survival (referred to as "donor" or "natal" sites) to areas of higher survival (referred to as "recipient" or "nursery" sites). This approach could achieve objectives 1 and 2 above. Nonetheless, if translocations are conducted at an appropriate scale for a sufficient number of years, some potentially negative consequences must be addressed. For example, donor populations may become unacceptably depleted or exhibit skewed sex ratios (as only females will be selected for translocation). Moreover, moving too many seals to recipient sites might result in overcrowding and adversely impact vital rates. For these reasons, some translocation measures will also be taken to achieve objective 3 above.

The proposed two-stage translocation approach is illustrated by the following. The NMFS Pacific Islands Fisheries Science Center (PIFSC) currently holds a permit to translocate weaned pups among NWHI subpopulations to improve their probability of survival. Unfortunately, all the primary NWHI subpopulations are experiencing relatively low juvenile survival (Figure 2) such that the potential efficacy of translocation amongst those subpopulations is uncertain. However, present conditions are favorable in the MHI, suggesting that the greatest positive effects of translocation could be achieved by moving weaned pups from the NWHI to the MHI. While juvenile survival in the NWHI is low, those seals that reach adulthood enjoy survival rates comparable to those in the MHI (Baker and Thompson 2007; Baker *et al.* in press). Thus, at present, the most effective scenario would likely involve moving weaned female pups from NWHI subpopulations to the MHI in order to increase the proportion surviving (first stage of translocation). Subsequently, animals that have achieved adult survival rate levels (*i.e.*, age 3 yr and older, following Baker and Thompson 2007 and Baker *et al.* in press) would be returned from the MHI to their natal NWHI subpopulations (second stage translocations). The latter action will serve to rebalance population distribution to avoid excessive depletion of donor subpopulations, ensure the MHI does not become over-populated, and prevent problems associated with male-biased sex ratios at donor sites. Further, should environmental conditions become more favorable in the future, this return translocation would serve to fortify subpopulation age structures, positioning them to exploit improved conditions and achieve positive growth. Without the second stage of the translocation process, donor subpopulations would likely become sufficiently depleted from prolonged low recruitment that population growth would be very slow, even in newly favorable environmental conditions.

It must be emphasized that while the preceding translocation scenario (*i.e.*, NWHI to MHI and return) is suggested by current conditions, future conditions may well dictate other approaches. For example, when juvenile survival is sufficiently high at any NWHI subpopulation, these NWHI subpopulations might be considered for receipt of translocated weaned pups. Likewise, if MHI conditions deteriorate significantly in the future, moving weaned pups from the MHI to the NWHI might be beneficial. Thus, it is critical to underscore that while the underlying translocation strategy is consistent, the particulars will necessarily be adaptive in accordance with prevailing monk seal demographics and environmental conditions. Furthermore, the realized success of translocations is uncertain. Because of the dynamic state of the system and the uncertainty of outcomes, the translocation program would be guided by a complex and adaptive decision framework.

Genetic considerations

Strong genetic population structure can imply local adaptation across a species' range. When planning translocations in such a context, the risk of diluting local adaptation is of critical importance. In contrast, the Hawaiian monk seal's lack of population structure coupled with observed levels of natural movement amongst subpopulations indicate that translocations may be conducted without fear of genetic consequences (Schultz *et al.* in press).

Decision framework

A host of complex and interacting issues arise from three fundamental features of the proposed translocation program:

1) The program will, by design, occur over a span of several years.
2) Environmental and, perhaps in smaller subpopulations, demographic stochasticity lead to variable and unpredictable monk seal survival rates over time and space.
3) This is a novel recovery strategy the outcomes of which are uncertain, and there is potential for unintended (including undesirable) outcomes.

The remainder of this document focuses on the design, execution, and evaluation of two-stage translocation supported by a decision framework and simulation modeling. The decision framework and modeling reflect an attempt to consider all relevant inputs to inform actions and foresee and minimize the risks of undesirable translocation outcomes.

The critical importance of the accumulated monk seal demographic database and the continued stream of annual monitoring data cannot be over-emphasized. Existing survival and age/sex structure information will be the primary basis for determining when to conduct translocations and between which subpopulations. Continued monitoring of both translocated and non-translocated individuals will provide the basis for project evaluation, informing the subsequent steps and reducing uncertainties of simulations.

The skeleton of the decision framework is depicted in two flow charts, one for each stage of translocation (Figure 5). A narrative follows, which travels through each step in the flow charts. Next, explicit risks of undesirable outcomes are described and components of the decision framework that mitigate those risks are presented.

Translocation of weaned female pups (Figure 5a)

The flow charts in Figure 5 are color-coded to help illustrate the decision-making process. Green boxes represent decision points or actions that progress toward translocation, whereas orange boxes indicate circumstances where translocations are suspended. Yellow boxes represent information inputs that influence decisions. Lastly, red numbers serve as references for orienting the following narrative with the chart.

Step 1 (in Figure 5a) is to evaluate whether there is a "substantial and consistent" difference in juvenile survival between at least two subpopulations. This indeed is the primary motivator for the entire translocation scheme. The two elements of this evaluation, "substantial" and "consistent" require further explication.

The magnitude of the difference in survival suggests a maximum expected benefit that could be conferred by translocation. For example, if survival for a given age class at two hypothetical subpopulations were 0.30 at site *a* and 0.70 at site *b*, then at best we could anticipate a 0.40 (0.70-0.30) improvement in the survival of seals moved from site *a* to *b*. The greater the survival differential, the more compelling the case is for translocation. However, establishing a concrete threshold for when translocation is worth doing is problematic, because we have insufficient experience with this intervention approach to reliably anticipate outcomes. Nevertheless, we require some guidelines to begin with, which will be refined as experience accumulates. The earliest age when translocations might occur is at weaning, and monk seals tend to achieve adult survival rates at approximately age 3 yr. Thus, an appropriate period for comparing survival amongst subpopulations is from weaning to age 3 yr. Initially, we will examine survival for this period among subpopulations but not hold to thresholds, which would be arbitrary if established *a priori*. While it could be argued that any improvement in survival is valuable, no matter how small, potential decrements to survival associated with translocation (see simulation modeling section) might subtract from the expected benefits of being placed in a more favorable environment. For initial trials the survival differential will be sufficiently large to allow the potential for considerable survival decrements to translocated seals without the action causing harm (*i.e.*, improvements should exceed decrements).

The concept that differential survival should be consistent before translocation is warranted arises from the observation that juvenile monk seal survival rates are notoriously variable among sites and from year to year. Previous analysis has shown that there is only weak autocorrelation in first year survival between years, such that poor survival in one year does not provide much predictive power about the next cohort's survival prospects (Baker and Littnan 2008). Not only do survival rates fluctuate, but estimates have associated error, in part because the cohort size at individual sites can be very low. In order to avoid having our translocation decisions constantly chasing last year's rates, we propose evaluating survival differential using the most recent available three years at each site. As with the magnitude threshold, this approach will be refined as information on outcomes is collected.

Thus, in Step 1, using the stochastic simulation model described in subsequent sections, we evaluate whether there is a sufficient differential in survival from weaning to age 3 yr measured over the past three years among subpopulations. If not, then continued monitoring of vital rates (**Step 2**) is prescribed. If yes, then we proceed to **Step 3**.

At **Step 3**, we ask whether the project has been ongoing for at least 3 years. If not, there are not yet any candidates for the return translocations, so we proceed directly to **Step 6**. However, if the project has been conducted for at least 3 years, we evaluate **Step 4**, whether return translocations of 3+ yr-old seals previously moved as weanlings are occurring as planned. Examples of conditions which might result in failure to return 3+ year olds as planned would be an emerging concern about a pathogen affecting either subpopulation, unanticipated logistical problems or other factors as described below. If seals are not being returned as planned, then weaned pup translocations are suspended (**Step 5**) until whatever is impeding return translocations is resolved. This decision is intended to both avoid overloading a recipient site with immigrants and preventing over-depletion and sex ratio imbalance at donor sites that are not being replenished.

At **Step 6**, the donor and recipient subpopulations are determined. This will typically be a simple matter of selecting the two sites with the lowest and highest survival, respectively. However, there may be cases where more than one site has similarly low or high survival, such that weaned pups could be drawn from or delivered to more than one site. As in Step 1, simulation modeling will be conducted to evaluate expected benefits associated with selecting various combinations of donor and recipient sites. If weaned pups have been translocated to the proposed recipient site in recent years, the survival performance of the former translocatees will inform this decision.

Step 7 is a critical juncture where the number of seals to be translocated is determined. This decision is influenced by numerous factors indicated by the yellow boxes. The *smallest* number indicated by any of these factors should be the *maximum* number considered for translocation. For example, the "number of weaned female pups in healthy condition" at the prospective donor site sets a clear upper bound on the potential number available for translocation. Likewise, logistical constraints (ship deck space, ship availability, funding, etc.) might also limit the number that can be translocated. Further, the number deemed prudent to translocate in any one year may be influenced by societal factors (especially in the MHI). Regardless, when the program is new, it will be prudent to start small with approximately 5 weaned pups, gradually increasing to at most 10 per year in the first several years. Finally, the capacity for the prospective recipient sites(s) to absorb a cadre of additional weaned pups must be considered. This will largely be assessed by evaluating trends in juvenile survival. For example, first year survival post-weaning appears to be sensitive to worsening conditions. Thus, if a trend towards deteriorating survival is observed, this would suggest translocating fewer numbers of new pups. Lastly, social factors (public attitudes) may indicate that receiving sites within the MHI can absorb fewer additional seals than might be concluded on biological grounds alone.

Once the target number is determined, seals will be captured at their natal sites (**Step 8**) and screened for a variety of health parameters including indications of infectious disease (**Step 9**). Health screening protocols evolve with techniques and perceived potential for specific diseases. However, PIFSC has established protocols for health screening translocated weaned pups, which are periodically reviewed and which have been applied as recently as 2009. Seals which do not pass the health screen will either remain at liberty at the natal site or will be brought into captive care if deemed in need of medical attention (**Step 10**). Those that pass the health screen will be transported to their destination, released, and closely monitored (initially with telemetry) (**Step 11**). Past experience has shown that direct release of weaned pups in appropriate habitat (*i.e.*, at sites where other pups have previously been weaned and survived) is a successful strategy (Baker *et al.* in review).

Translocation of seals age 3 yr and older (Figure 5b)

The second stage of the proposed translocation involves repatriation of seals, previously translocated as weaned pups, which have achieved adult survival rates (3+ yr-olds). Figure 5b depicts the flow chart for this process, with color-coding and notation conforming to that in Figure 5a.

Step 1 is reached when translocations have occurred three years or more previously, so that there are potential translocatees available for repatriation. At **Step 2**, we assess whether the survival prospects for adults in the seals' natal region are roughly as high or higher than in the current location. The reasoning here is that while juvenile survival varies greatly among subpopulations, adult rates tend to be more similar and less variable. For example, although juvenile survival is currently much lower in the NWHI than in the MHI (Figure 2), adult survival in the NWHI is comparable or just slightly lower than that in the MHI (Baker *et al.* in press). Thus, the two-stage translocation effectively protects subjects from the high mortality they would have otherwise experienced as juveniles in their natal regions, and returns them at an age when they will likely experience relatively high survival. The two translocations, then, confer a net benefit on translocatees even if they experience slightly lower survival as adults when repatriated in their natal regions. The expected magnitude of this net benefit will be assessed using simulation modeling as described in subsequent sections.

Alternatively, if adult survival at the natal region is considerably lower, then return translocations would be suspended (**Step 3**) and additional weaned pup translocations from the donor population in question would also cease (see Figure 5a, **Step 5**). It is conceivable that in rare cases other factors might provide a compelling incentive for translocating 3+ yr old seals even if adult survival at the natal site is sub-optimal. For example, addressing an imbalanced sex ratio or some other deficit might influence the disposition of these young female seals. If adult survival at the natal region remains comparable to, or higher than, the current location, we proceed down the path to return previous translocatees to their natal region (**Step 4**). The number of age 3+ yr-olds to return is simply determined as the number of surviving previously translocated weaned pups (**Step 5**).

The next important decision is to confirm that returning seals to the site of origin is indeed appropriate and prudent at the present time (**Step 6**). This deliberation is influenced by multiple factors (yellow boxes). For example, if seals have been returned in previous years, the survival performance of those earlier returnees will be considered before additional seals are repatriated. More broadly, the capacity of the natal region to absorb returnees will be assessed as indicated by survival rates of all ages at the site, as well as current abundance relative to historical levels. Disease risk is another consideration. If a known disease is present at the natal subpopulation, but is absent from the seals' current location, then it would not be appropriate to expose returnees and thus risk their survival. If it is deemed inadvisable to return seals to the preferred (natal) location, then an alternate nearby location may be chosen, so long as that location is deemed prudent according to the above criteria. Finally, male-biased sex ratios have led to male aggression-related mortality in the past, and interventions to adjust sex ratio have successfully lowered this threat (Johanos *et al.* 2010). Thus, there may be cases where returning seals to a site, not necessarily their birth location, could be used to ameliorate male-biased sex ratios. If no appropriate release location is identified, then return translocations of 3+ yr-olds will be suspended (**Step 3**).

Once the release location(s) have been confirmed, the subject seals will be brought into captivity (**Step 7**, *in situ* pens/cages in the NWHI; permanent captive facilities in the MHI). At this point, the seals will be health screened as described above and also held in quarantine for a prescribed period; likely approximately two weeks, depending upon veterinary protocols to be developed (**Step 8**). The primary purpose of quarantine is to confirm absence of active disease and minimize the chance of transmitting a disease into a return site where that disease may be absent. The quarantine period may be shortened when moving animals between subpopulations where disease surveillance indicates that the prevalence of exposure to a suite of pathogens is equivalent. Quarantine is expected to be most important when moving seals from the MHI to the NWHI, as some diseases may occur in the former region but not the latter because of the presence of feral and domesticated animals in the MHI.

Seals which fail to pass the health screen or quarantine will be released at the capture site or brought into captive care if appropriate (**Step 9**). Otherwise, they will be transported, released and closely monitored (initially with telemetry)(**Step 10**).

Minimizing risk of undesirable outcomes

A variety of risks are inherent in any intervention in wild populations, including the proposed two-stage translocation. Risk minimization will be achieved through program design, intensive monitoring and evaluation, and the adaptive decision framework described above. Below, we address how the risk of an extensive list of conceivable potential ill effects will be minimized.

Table E-1. Risks and concerns that may affect the outcome and evaluation of two-stage translocations in Hawaiian monk seals.

Issue	Risk or Concern	Mitigating Factors
Condition of weaned pups (*e.g.*, axillary girth), is positively related to survival prospects.	Selection of weaned pups for translocation may not be representative (i.e only viable, healthy pups will be selected), so that project evaluation may be difficult.	Small, but otherwise healthy pups will not be excluded from translocation. Only non-viable, emaciated or wounded animals will be avoided. Post-hoc analysis will control for condition of both translocated and non-translocated pups.
Depletion of donor subpopulations.	If weaned pups are continuously taken from a site, abundance may fall to an unacceptably low level, with the potential that: i) Seals no longer play a "functional" role in the system. ii) Competitors may occupy the monk seal niche and inhibit population re-establishment. iii) "Empty" environment could be a wasted opportunity for growth if intra-specific competition is low.	Depletion should only be short-term and moderate because 3+ yr-olds will be returned to the donor population. This, in fact, should increase rather than deplete the donor population after return translocations commence. Moreover, should intra-specific competition lessen at the donor site, juvenile survival should consequently increase. This will reduce the survival differential between sites and automatically regulate further weaned pup translocations.
Development of male-biased sex ratios	Removal of female pups will eventually manifest in male-biased sex ratios, leading to increased male aggression toward adult females and juveniles.	Weaned female pups will be returned to natal sites prior to sexual maturity. Presumably they will have enjoyed higher survival than (non-translocated) males. Ultimately, the two-stage translocation should result in some female bias for effected cohorts. If in fact the translocated females fare poorer than their male counterparts or cannot be repatriated for any reason, weaned pup translocations would be suspended as described in the decision framework. This could result in male bias for a few affected cohorts, but this would be a small portion of the total population.
Capacity of recipient site to absorb immigrants.	Overshooting carrying capacity could lead to a crash of the recipient population.	Recipient site demographics will be closely monitored, especially for declining juvenile survival. If this is observed, the differential survival between donor and recipient sites decreases, so that translocations slow or cease, thus correcting the problem.
Translocated seal survival	Weaned pups taken from their natal sites may not fare as well as natives at their host site. Returned 3+ yr-old returnees may not survive as well as those who have survived from birth at their natal site.	Past experience (Baker *et al.* in review) has shown that recently weaned pups are amenable to translocation and have survival rates indistinguishable from pups born at release sites. Sites where pups have been weaned and survived will be selected as release locations for weaned translocation pups. Experience translocating seals around 3 years of age is limited. Repatriates to their

		natal regions may have both disadvantages and advantages relative those that have grown up there. Three-year-old seals may experience greater effect of capture stress than has been the case with weaned pups. Returnees may be disadvantaged by having to learn to forage in a new area, which may have less prey availability than where they grew up. However, because returnees spent their first 3 years in more favorable habitat, their body condition should be better than non-translocated seals in their natal region, thus providing a survival advantage. In both cases (weaned pups and returnees), survival will be monitored and translocation plans appropriately adapted as described in the decision framework.
Infectious disease	Translocating seals may result in spreading disease faster than would occur naturally.	Health screening of all translocated seals, coupled with appropriate quarantine of returnees will minimize risk of transporting infectious agents. Moreover, disease surveillance will be ongoing throughout the species range to detect emerging disease outbreaks. At present, there does not appear to be strong differences in exposure throughout the range, perhaps with the exception of some diseases (leptospirosis, toxoplasmosis) more prevalent in the MHI than the NWHI.

Simulations to evaluate benefits from two-stage translocations

Model Design

The monk seal stochastic simulation model was used to compare and evaluate the expected outcomes from a representative set of translocation scenarios. Details of the model structure and mechanics are provided in Harting (2002) and only the fundamental features are described here. At its core, the model is a mechanistic, stochastic, metapopulation model with provisions for handling uncertainties in input parameters and modeled processes. The model is heavily data driven, capitalizing on the demographic and life history data collected over more than two decades in the NWHI and, more recently, the incipient demographic data set for the MHI. Necker and Nihoa Islands (NWHI) are relatively data poor and have historically comprised a small portion of total abundance, and are therefore not included in simulations. The model provides multiple options for simulating natural perturbations (survival catastrophes, birth catastrophes, shark predation, and aggressive male interactions) and management interventions (captive rearing/release, translocations, shark removals, and other). It produces a diverse array of outputs suitable for evaluating simulation outcomes including abundance, realized growth rate, multiple demographic descriptors, and assorted metrics specific to whatever intervention scenario was executed. The primary output is site-specific, with summary diagnostics for the entire system and the two main regions (NWHI and MHI).

For the purposes of this analysis, certain model components were disabled, including the option for density dependent adjustment of demographic rates. While that feature of the model is certainly important when performing long-term projections, the precise manner in which density dependence operates on the monk seal population is unknown and its influence can overwhelm and obscure the effects of all other factors included in the simulation scenario.

For the NWHI, age-specific survival rates used for model input were derived from fitting the Siler survivorship curve to observed rates from the most recent three data years. Separate curves were fit for each of the 6 sites. For the simulations, parameter uncertainty was handled by random sampling Siler parameters from the variance/covariance matrix from the parameter fitting. Age-specific reproductive rates were estimated from pooling pupping data from 1990 to the present using methods described in Harting *et al*. (2007). As with survival rates, parameter uncertainty was handled by randomly sampling a unique set of correlated parameters from the fitted distributions. In the model, survival and reproduction are determined stochastically for each individual in the population by binomial sampling (testing a uniform random number in the range [0,1] against the age-specific survival rate). Migration is also determined stochastically for each individual according to the fitted movement rate for each age class. Each simulation was initialized with the most recent starting age/sex distribution for each NWHI site.

As compared to the NWHI, data from which to estimate vital rates and population composition are much more limited for the MHI. A detailed description of the methods used to fit both survival and reproductive rates for the MHI are provided in Baker *et al.* (in press). Where data were lacking (*e.g.*, reproductive rates of older MHI females), some inference and extrapolation was necessary based on patterns observed in the NWHI. Uncertainty in parameter estimates was handled in the same manner as for the NWHI, with unique parameters drawn from their fitted distributions at the start of each simulation.

Translocation Scenarios

As described in the decision framework section of this document, the specific translocation scenario to be undertaken in a given year will be determined according to the most recent data available for each subpopulation. Results from preceding translocation efforts, logistics to accomplish the translocation and other considerations will also enter into the decision-making calculus. In a given year, the optimal translocation scenario might involve any combination of single or multiple donor and nursery sites. Further, the number of seals collected and translocated to each site will vary. It is not our intent to present and evaluate the full complement of translocation scenarios that might be undertaken, but rather to present a small set of representative scenarios that illustrate the salient aspects of this intervention strategy and highlight some of the variables and uncertainties that influence the expected outcome. In practice, prior to initiating an action, additional simulations and ancillary analyses will be undertaken to inform NMFS about the relative benefits that might accrue from various translocation scenarios in a given year.

We present results from nine scenarios. These include one "baseline" scenario that involves no translocation and which serves as the basis of comparison for the other scenarios. This scenario is indicative of what would be expected if current vital rates remain applicable for the duration of the 10-year model projection, and no major perturbations or interventions alter the population trajectory.

The remaining simulations are divided into two sets of four simulations each: one set of cross-region translocations (from French Frigate Shoals (FFS) to MHI), and another set of within-NWHI translocations (FFS to Laysan Island (LAY)). These sites were selected primarily based on the current survival differential of the species' main breeding sites as estimated from the most recent (2010) data. Considering only the NWHI, FFS has consistently had the poorest juvenile survival of any site (l_3 = 0.137), while LAY currently has had much better juvenile survival rates (l_3 = 0.331), although , as with other NWHI sites, LAY has historically demonstrated considerable inter-annual variability (Figure 2). In contrast to all NWHI sites, the MHI has demonstrated the best juvenile survival of any breeding site (l_3 = 0.641).

For all scenarios, we simulated the collection of 10 female pups annually for 5 years at FFS and subsequent release at the nursery site (MHI or LAY). Although the model allows for mortality while in transport, for these simulations there was no deduction for captive mortality and the number of seals released was the same as the number collected. This is consistent with the very low levels of translocation mortality reported by Baker et al. (in review). In actual translocations to the MHI, the specific island and release site will be chosen on the basis of past suitability for native pup survival as well as other (social) considerations. However, for purposes of estimating demographic rates, there is no distinction among sites in the MHI and hence the MHI release site was treated generically for the translocation simulations.

Once released, the translocated pups are presumed to merge with the native-born seals, but the model has provisions for a first-year survival decrement of translocatees as compared to the native born seals at the release site. The concept underlying this survival decrement is based primarily on data supporting a positive relationship between weaning girth and first year survival, although the shape of that relationship varies over time and space (Baker 2008). Weaned pups in the MHI exhibit higher survival than in the NWHI and also MHI pups wean in far better condition on average than in the NWHI. Therefore, if we were to translocate NWHI weaned pups to the MHI, we would not necessarily expect them to enjoy the average survival rate of native pups, but rather the survival rate of *similarly-sized* pups in the MHI, as predicted by the fitted relationship between size (girth) and survival in the MHI. The average girth of 70 weaned pups born at FFS during 2007-2009 was 103.7 cm. Pups in the MHI with this girth would have an expected survival rate of 0.69. The overall survival rate of pups born in the MHI is 0.77, so that the expected decrement for FFS pups translocated to the MHI would be 0.69/0.77 = 0.90. This value was used for the survival decrement in certain translocation scenarios. To encompass the full range of possibilities, additional scenarios were run using no survival decrement for the first year after release at the nursery site. In a review of a variety of past translocation experiences, Baker *et al.* (in review), found that translocated weaned pups enjoyed survival rates indistinguishable from native born seals in the same area.

For all simulation years subsequent to the first year after release, translocated seals shared the same survival rate as native-born seals with survival determined stochastically as described above. However, the model maintains separate "accounting" for the translocated seals so that the number of seals stochastically surviving to each age is tracked.

The model provides the option to return seals to their natal site at a specified age. For all of the simulated translocations described herein seals were returned at age 3. At this stage of the simulations, another survival decrement can be optionally applied to represent differential success relative to non-translocated seals left on site. As with the previous nursery site survival decrement, the return decrement applies only to the first year after release. The appropriate magnitude for this decrement is uncertain, but multiple factors might act to steer this adjustment in opposing directions. Returning seals will initially be unfamiliar with the new environment and it might take some time for them to orient to prime foraging and haulout areas. The available prey may also differ between the two areas. Returning seals may have less experience with sharks and competitors, especially if they grew up in the MHI. Finally, because there has been little experience translocating seals of this age, there may be some increased mortality due to stress of captivity. In contrast to the preceding negative considerations, and in accordance with the intent of the translocation to place seals in a more favorable environment, returning seals may be larger and healthier than seals that developed on site. This factor would positively affect survival of these seals.

Due to uncertainty regarding the relative roles that each of these factors might play in the survival prospects of returning seals, the simulations allowed for two different return decrements: no decrement (*i.e.*, same survival as native born seals), and a 29% decrement (multiplier of 0.71) relative to native seals. The latter decrement was derived from observations of the survival of seals collected at FFS for captive care treatment and later released at Kure Atoll or Midway Atoll. While those seals had a survival rate of 71% as compared to native seals, that reduction may be more severe than is expected in the current case. The captive care seals had no foraging experience prior to release, and were age 1 yr (rather than age 3 yr) when released. Nonetheless, we believe that the two values we used (100% and 71% of native survival) are reasonable estimates to bracket the range of plausible decrements that could be expected.

Combining the two values for each of the two survival decrements, and allowing for the two different geographic scenarios (FFS to MHI, and FFS to LAY), gives a total of 8 translocation scenarios plus the single baseline (no translocation) scenario (Table 2).

Table 2. Simulation scenarios to evaluate expected outcomes from two-stage monk seal translocations. All scenarios involved 10 seals translocated per year for 5 consecutive years, with all survivors returned to their natal site at age 3 yr. Populations were initialized at current age/sex status and projected forward 10 years.

Survival multipliers 1st year after release*		Locations (natal site to nursery site)	
Nursery (recipient) site	**Natal (source) site**	**FFS to MHI**	**FFS to LAY**
1.0	1.0	Scenario 1a	Scenario 2a
0.90	1.0	Scenario 1b	Scenario 2b
1.0	0.71	Scenario 1c	Scenario 2c
0.90	0.71	Scenario 1d	Scenario 2d

* Values in each cell are multiplied by operative rate for like age-class seals at the release site to provide an adjusted survival rate applicable to the treated seals.

Metrics for evaluation

It is important that a proper metric, or set of metrics, be identified to evaluate the outcomes from the translocation simulations. In the long term, critical metrics include total population abundance, metapopulation structure and extinction risk. These measures clearly depend on a wide range of factors (many of which are represented in the model along with their associated uncertainties), which collectively account for the substantial variability in outcomes characteristic of long-range projections. Although conducting long-range projections, and perhaps full population viability analysis (PVA), is vitally important in the strategic design of monk seal recovery, it is not our intent to undertake such an analysis here. Rather, we are primarily interested in near-term projections and metrics that are most useful for revealing the influence of the proposed translocations, and which minimize the confounding influence of other factors (density dependence, environmental stochasticity, etc.) that might mask the directs effects of the translocations.

Among the obvious metrics for assessing results from the simulations is raw population abundance or realized growth rate from the first to final years of the simulations. While these values are certainly informative, we believe that they can be misleading because they fail to address one of the salient limitations in the NWHI subpopulations, that of a depauperate age structure. As described in the background section, the protracted period of low juvenile survival has led to an ageing breeding population and dwindling cohort sizes. Barring a natural improvement in juvenile survival, or an intervention that addresses the same, that pattern is expected to continue for the foreseeable future. Within that context, it is appropriate that the simulations be evaluated according to some metric associated with population age structure. *Reproductive value* (v_x), and the related *population reproductive value* (V_{pop}), provide informative measures for this purpose. Age-specific reproductive value (Eqn. 1) reflects the probable future reproductive output of an individual female now of age x in terms of newborn equivalents. This value is given by:

$$v_x = \frac{\lambda^x}{l_x} \sum_{i=x}^{\max} \frac{\phi_i}{\lambda^i} \qquad (1)$$

where λ is the intrinsic growth rate, l_x is the survivorship to age x, and ϕ_x is the age-specific net maternity function ($l_x m_x$).

Reproductive value is a particularly useful descriptor for comparing the relative demographic contributions expected from individuals of different ages. It incorporates information on both the likelihood of survival to each reproductive age, as well as the expected reproductive output of an individual of age *x* and all future ages. It is less useful for comparing across lifetables (that is, among different populations) since it is scaled in terms of newborns for the unique lifetable applicable to that particular site. For monk seal populations, v_x attains a maximum at around age 5-7, but varies in maximum value from over 7 newborn equivalents (FFS) to under 3 newborn equivalents (MHI) (Figure 6). The difference between these two sites is largely attributable to the fact that at FFS, newborn pups stand a poor chance of reaching the age of reproductive maturity, whereas the prospects for pups born at the MHI are relatively high.

Whereas v_x is a property of the lifetable and does not reference the current population state, *population reproductive value* (V_{pop}) extends the concept by incorporating information on the current population size and age/sex composition. This parameter is the sum of the age-specific reproductive values for all of the females currently in the population:

$$V_{pop} = \sum_{x=0}^{\max} v_x n_x \qquad (2)$$

where v_x is the age-specific reproductive value of an individual of age *x*, and n_x is the number of individuals of age *x* currently in the population. One can think of V_{pop} as analogous to the quantity of potential energy stored in the population, which is likely to translate into future pup production. This metric is particularly *apropos* for our purposes because we do not believe that any single intervention, including translocations, will be capable of effecting a major improvement in total population abundance. We do believe, however, that by targeting our interventions on age-structure adjustments, we can fortify the population so that it is capable of a rapid response should environmental conditions more conducive to population growth eventually arise.

Using these two demographic measures as our primary metrics, what we hope to achieve through translocation is to increase the number of females in those age classes having the highest v_x. In aggregate, those additional females will act to increase V_{pop}. This concept is best illustrated graphically (Figure 7). Here we see the resulting age structure from a hypothetical translocation scenario, as compared to the baseline, no-translocation projection. The increase in number of females aged 5-9 yr corresponds to the age classes with the highest v_x at FFS (dotted line and right *y*-axis). By taking those seals to a more favorable nursery site, they will effectively circumvent the intense survival bottleneck affecting non-translocated seals left on-site.

Simulation Results

Effects of the translocations at the nursery site

Because the translocated seals were returned to their natal site at age 3 yr for the simulations, the effects of the translocations at the nursery site were ephemeral (Figure 8a). As expected, final abundance at the nursery site was the same with or without the translocations, but the mean population trajectory was elevated while the project was underway (years 1-8) as compared to the baseline trajectory. This observation holds true for all 8 translocation scenarios. This pattern of no net effect is based on the assumption that the addition of a small number of seals at the nursery site (maximum of 30 at any time, age pup through age 2) will not result in density-dependent reductions in survival at the nursery site. Further, the imported seals were "removed" prior to attaining reproductive maturity and therefore produced no pups at the nursery site. Because the translocations elicited no net change at the nursery site, the remainder of this review will focus on effects at the natal site.

Effects of the translocations at the natal site

For all scenarios, the natal population (FFS) was initialized at the current (2010) population size of 194 seals. The mean abundance declined under all simulation scenarios, including both the baseline (Bsl) and all translocation scenarios. In the no-translocation scenario (Bsl Figure 9), the abundance dropped to 93 seals at the end of the 10-year projection (52% decline). The projected decline is largely driven by loss of senescent seals and a declining cohort size from fewer breeding females. Although the benefits derived from translocations were not sufficient to fully compensate for the population decline forecast for this site, the final abundance with translocation ranged from 96 to 112 seals, depending on which site was used as the nursery (MHI or LAY) and which set of survival decrements was applied. The highest abundance (112 seals) was achieved when the seals were taken to the MHI and no survival decrements were applied.

When viewed in terms of their effects on *population reproductive value* (V_{pop}), returns from the simulated translocations were more impressive. However, as with final abundance, none of the translocations were sufficient to offset the expected decline from all other factors (Figure 10). Initially (year 1) the FFS population has V_{pop} of approximately 360 newborns (this value varies each simulation due to random age assignments of seals having unknown ages, such as those first identified as adults). Under the no-translocation scenario (Bsl), the V_{pop} is expected to decline to less than 165 newborn equivalents. In contrast, under the various translocation scenarios, V_{pop} ranged from 181 to 263 newborn equivalents. As with final abundance, the greatest returns were achieved through the MHI translocation scenarios (T1a to T1d), but even the least favorable translocation scenario (T2d; LAY with both survival decrements) produced a 10% improvement in V_{pop} as compared to the baseline scenario.

Yet another way to view the returns from the translocations is by inspecting the proportional change in V_{pop} from year 1 to year 10 of the scenarios (Figure 11). With no intervention, in 10 years the FFS subpopulation is expected to have only about 45% of the reproductive potential of the initial population. Under the most favorable translocation scenario (T1a), approximately 73% of V_{pop} is preserved, with the remaining translocation scenarios yielding between 50% and 70%.

Interpretation of Simulation Results

It is evident from the simulations that FFS is likely to undergo a significant decline in both abundance and reproductive capacity with or without focused intervention. The best that can be achieved through translocation is to moderate the decline and reinforce the population so that it has enough resilience to capitalize on improved conditions should they occur, and to initiate a slow natural recovery which might be bolstered by additional interventions. The simulations described above are all focused on a single subpopulation, FFS, which currently has the poorest juvenile survival and lowest intrinsic growth rate of any breeding site. The general pattern described for FFS, along with the expected benefits from translocation, are applicable to all of the NWHI subpopulations. The magnitude of the benefit conferred through translocation will vary according to the current status of the subpopulation and the survival differential between whichever natal and nursery site are selected for treatment, as based on the decision framework presented above.

The specifics of the 8 simulation scenarios we described were chosen to illustrate the range of benefit that might be realized from two-stage translocation. Although the specifics of these scenarios were hypothetical, it is worth considering which among them we believe to be the most realistic. For the FFS to MHI translocations (T1a – T1d), there is a reasonable expectation that the first survival decrement (0.90 multiplier for the first year after release) will apply due to the smaller size and inferior condition of FFS pups relative to MHI pups. The post-return decrement is less certain; it is likely that the 0.71 survival multiplier is overly severe, as it was based on a set of captive care seals released at age 1 yr and having no prior foraging experience. These observations lead us to conclude that the actual benefit from translocation to the MHI would be intermediate between scenarios T1b and T1d.

We can apply the same logic to the LAY translocations (T2a to T2d). First, the initial decrement is likely to be less than the 0.90 multiplier because seals born at FFS and LAY are more similar in size and condition than are seals born at FFS and MHI (as used to calculate the 0.90 decrement). Therefore the actual multiplier is expected to be less severe than that prescribed by the 0.90 value used for the MHI. Similarly, because the seals will be returned to habitat that is similar to that in which they developed (*e.g.,* in terms of predators and competitors), the returning decrement could arguably be less severe than that for seals transferred from the MHI to FFS. It is reasonable to expect that *some* decrement will be incurred as the seals orient to the new area, so that the correct value for the second multiplier will lie between 0.71 and 1.0 but probably on the higher end of that range. This logic leads us to conclude that the most realistic scenario is a composite of scenarios T2a, T2b and T2c.

There is another very important consideration with regard to the FFS to LAY translocations and which may be applicable to any within-NWHI translocation scenario. In contrast to the MHI, each of the NWHI subpopulations is currently declining. Consequently, it is questionable whether any of these sites could accommodate additional seals without causing further depression in survival rates. Further, substantial inter-annual variability in vital rates in the NWHI may make it difficult to identify which combination of sites might reliably produce a positive outcome in a given year. This same variability could also make it difficult to discern whether any downturn in demographic performance was related to translocation efforts or attributable to normal stochastic variation. There are, however, clear advantages to within-NWHI translocations. Confining the interventions to the NWHI circumvents potential problems with human-seal interactions and public resistance to importing, even if only temporarily, additional seals. Disease and quarantine concerns might also be less intense in the context of exclusively within-NWHI translocations.

Addressing uncertainty in post-return decrements to survival

The simulated benefits of two-stage translocations are strongly influenced by the magnitude of decrements applied to survival of translocated seals after each translocation stage. The decrement values used for the simulations were extrapolated from the best available data and are a reasonable expected range based on existing information. There has been considerable experience translocating weaned pups (Baker et al., in review) and much analysis of the relationship between weaning girth and survival (Baker 2008), so that the expected range of survival decrements applied to translocated weaned pups is well supported. However, there is much greater uncertainty associated with the decrement applied to 3-yr-old seals returned to their natal subpopulations. Given this uncertainty, it is informative to consider how large a survival penalty translocated seals could incur before their survival matched, or was inferior to, that of non-translocated seals at the natal site. This threshold decrement value can be estimated from observed survival rates for seals at the natal and nursery sites (Table 3).

Table 3. Age-specific survival rates for recent years at FFS, LAY and MHI. The rates in the first column represent survival from weaning to Age 1.

	Weaning to 1 yr	**1 yr to 2 yr**	**2 yr to 3 yr**	**3 yr to 4 yr**
FFS	0.359	0.567	0.941	0.895
LAY	0.681	0.537	0.917	0.938
MHI	0.841	0.859	0.910	0.891

In the above simulations, FFS served as the donor site and MHI or LAY served as the nursery sites. Seals were returned seals to their natal site at age 3 yr, at which point a survival decrement was applied for the first year after return (from age 3 to 4 yr). Therefore the value of greatest interest for evaluating translocation is survivorship from weaning to age 4, designated as l_4* (the asterisk serves to distinguishes this parameter from the customary l_4 which measures survival from birth to age 4), which is the product of the age-specific survival rates in Table 3):

$$l_4^* = p_0 * p_1 * p_2 * p_3 \qquad (3)$$

where p_0 is the survival rate from weaning to age 1 and p_1-p_3 s are age-specific survival rates for the respective ages. Substituting the survival rates for ages 0-3 yr at FFS (Table 3) into Equation 3 gives $l_4^* = 0.171$. Accordingly the objective of the translocations is to improve on that rate such that the translocated seals do better than those "control" seals left at the natal site.

The operative survival schedule for the translocated seals is a composite of the survival rates for ages 0-2 yr at the nursery site, and age 3 yr at the return site. Additionally, we have incorporated two survival decrements that apply, respectively, to age 0 yr (weaning, when the seals are first released at the nursery site) and age 3 yr (after they are returned). The operative survival schedule for the translocated seals is then:

$$l_4^* = (p_0*d_1) * p_1 * p_2 * (p_3*d_2) \qquad (4)$$

where p_0, p_1, and p_2 are the survival rates for weaning through 2 yr at the nursery site; p_3 is the survival of age 3 yr seals at the return site; d_1 is the survival decrement for pups during the first year after release, and d_2 is the survival decrement at the return site for the first year after release.

The most severe d_1 survival decrement used for the simulations was 0.90, derived from examining the survival of MHI pups of comparable girth to average FFS pups. However, because the difference in weaning girths among the NWHI subpopulations is far less than the difference between NWHI and MHI pups, a d_1 value of 0.90 may be overly severe for translocations between NWHI subpopulations. Yet, to determine survival decrement thresholds, we can conservatively set d_1 to a fixed constant = 0.90, leaving only decrement d_2 as an unknown:

$$0.171 = (p_0*0.90) * p_1 * p_2 * (p_3*d_2) \qquad (5)$$

where 0.171 is the aforementioned l_4^* for FFS-born, non-translocated seals. This equation serves as the basis for calculating the threshold return decrement, d_2, that demarcates a net benefit from net harm associated with two-stage translocation.

For FFS to MHI translocations, substituting MHI survival rates for p_0 through p_2, and the FFS rate for p_3 in Equation 5 gives:

$$0.171 = (.841*0.90) * 0.859 * 0.910 * (0.895*d_2) \qquad (6)$$

Solving for d_2 gives a return decrement value of 0.324. This means that, given recent survival rates at FFS and MHI, seals translocated from FFS to MHI as pups and returned at age 3 yr would do better than non-translocated seals if their realized survival for the first year after return is at least 32% that of non-translocated seals.

For FFS to LAY translocations, *s*ubstituting LAY survival rates for p_0 through p_2, and the FFS rate for p_3 gives:

$$0.171 = (.681*0.90) * 0.537 * 0.917 * (0.895*d_2) \qquad \text{(Eq. 7)}$$

Solving for d_2 gives a return decrement value of 0.635. This means that, given recent survival rates at FFS and LAY, seals translocated from FFS to LAY as pups and returned at age 3 yr would do better than non-translocated seals if their realized survival for the first year after return is at least 63% that of non-translocated seals.

The preceding calculations of expected survival decrement thresholds are point estimates which do not account for high inter-annual variability which characterized monk seal survival, or the demographic stochasticity associated with small sample sizes (reflected in Fig. 9-11). Nonetheless, these estimates suggest that there is a sizable safety buffer for MHI translocations and a marginal safety buffer for within-NWHI translocations even if the lowest value used in the above simulations (0.71) was overly optimistic. The actual degradation in survival could be more severe than assumed and the translocated seals are still likely to perform better than seals left at their natal site.

The intent of two-stage translocation is not to merely "break even" but rather to confer enough benefits on the managed subpopulation to warrant the effort, expense and risk involved. Whether or not a particular translocation plan is advisable must still be determined according to the expected benefits (abundance, V_{pop}, and other metrics) likely to accrue from implementing that plan. However, the threshold values provide a valuable reference for maintaining a standard of "doing no harm" with the proposed program.

Under two-stage translocation, the earliest data about the actual return survival decrement would not be available until the fourth year of the project, when the survival of the first group of 3-yr-old seals returned to their natal sites would be evaluated. Relevant information could, however, be collected by initiating some limited experimental translocation of juvenile seals. The experiment may first involve moving a small number of juveniles (at least age 3 yr) among areas of the NWHI where foraging conditions or success are thought to be comparable. This would help evaluate the potential combined effects of translocation on this age-class, without the confounding influence of a marked change in habitat quality. Subsequently, older juveniles might then be moved from an area with relatively low competition and predator densities (e.g., the MHI at present) to areas with greater competition and higher predator densities (NWHI). This would provide information about how older juveniles respond to being released in unfamiliar environments with more challenging conditions relative to where they grew up.

Conclusion

The two-stage translocation strategy described and analyzed above is but one tool in a suite of interventions now planned or proposed to promote monk seal conservation. Unfortunately, none of these interventions, whether undertaken singly or in concert, are sufficient to fully compensate for the projected decline in the species. Although we know of no direct precedents for two-stage translocation, and there are many unknowns that accompany its implementation, we think that this approach will be indispensable to the overall recovery effort.

Two-stage translocation is a novel strategy that should produce not merely an ephemeral boost in abundance, but, more importantly, will preserve essential reproductive potential within the population. This intervention will be flexible and adaptable, with the specific form it assumes each year informed by the most recent data on demographic performance at each site. This flexibility will allow demographic issues throughout the system to be addressed, whereas some prior interventions have focused on specific mortality factors at individual sites. Those interventions are vitally important to the welfare of specific subpopulations, but they lack the scope to insulate the population from further system level decline and perhaps extinction.

The decision framework represents how the translocation program is expected to be conducted. Similarly, the simulations provide the best assessment of the returns that could be achieved through translocation. Once the program is underway, both the model inputs and details of the decision framework will be iteratively refined to reflect new observations from incoming data. Accordingly, we intend to embark on this project with the utmost caution, initially as a small-scale experiment to refine the protocols, evaluate the early results, and modify and scale up the program as appropriate.

The need to identify beneficial interventions does not end with translocation, as the NMFS will continue to identify other creative strategies to arrest the population decline.   But such a solution has proven elusive, and given the current trends, it would be imprudent to defer decisive action while the quest for that ultimate remedy goes forward. It is our hope that the need for translocations, along with the need for all other intrusive measures, will eventually yield to natural processes, as the trajectory of the monk seal population begins its ascent to a sustained and full recovery. In the interim, it is incumbent on NMFS to take the steps necessary to ensure that the population is not indifferent to any improvement in natural conditions, but retains the capacity to respond accordingly.

References

Antonelis GA, Baker JD, Johanos TC, Braun RC, Harting AL (2006) Hawaiian monk seal (*Monachus schauinslandi*): status and conservation issues. Atoll Research Bulletin 543:75-101.

Baker JD, Johanos TJ (2004) Abundance of the Hawaiian monk seal in the main Hawaiian Islands. Biological Conservation 116:103-110.

Baker JD, Thompson PM (2007) Temporal and spatial variation in age-specific survival rates of a long-lived mammal, the Hawaiian monk seal. Proceedings of the Royal Society B 274:407-415.

Baker JD, Polovina JJ, Howell EA (2007) Apparent link between survival of juvenile Hawaiian monk seals and ocean productivity. Marine Ecology Progress Series 346:277-283.

Baker JD (2008) Variation in the relationship between offspring size and survival provides insight into causes of mortality in Hawaiian monk seals. Endangered Species Research 5:55-64.

Baker JD, Littnan CL (2008) Report of the Hawaiian Monk Seal Captive Care Workshop, Honolulu, Hawaii, June 11–13, 2007. Pacific Islands Fish. Sci. Cent., Natl. Mar. Fish. Serv., NOAA, Honolulu, HI 96822-2396. Pacific Islands Fish. Sci. Cent. Admin. Rep. H-08-02, 42 p.

Baker JD, Harting AL, Wurth TA, Johanos TC (In press) Dramatic shifts in Hawaiian monk seal distribution predicted from divergent regional trends. Marine Mammal Science Published Online: May 26 2010 2:27AM DOI: 10.1111/j.1748-7692.2010.00395.x.

Baker JD, Becker BL, Wurth TA, Johanos TC, Littnan CL, Henderson JR (In review) Review of translocation as a tool for conservation of the Hawaiian monk seal.

Harting AL (2002) Stochastic simulation model for the Hawaiian monk seal. PhD thesis, Montana State University, Bozeman, MT.

Harting AL, Baker JD, Johanos TC (2007) Reproductive patterns of the Hawaiian monk seal. Marine Mammal Science 23:553-573.

IUCN (1998) Guidelines for re-introductions. Prepared by the IUCN/SSC Re-introduction Specialist Group. IUCN (http://www.iucnsscrsg.org/).

Johanos TC, Becker BL, Baker JD, Ragen TJ, Gilmartin WG, Gerrodette T (2010) Impacts of sex ratio reduction on male aggression in the critically endangered Hawaiian monk seal *Monachus schauinslandi*. Endangered Species Research 11:123–132.

Polovina JJ, Chai F, Howell EA, Kobayashi DR, Shi L, Chao Y (2008) Ecosystem dynamics at a productivity gradient: A study of the lower trophic dynamics around the northern atolls in the Hawaiian Archipelago. Progress in Oceanography 77:217-224.

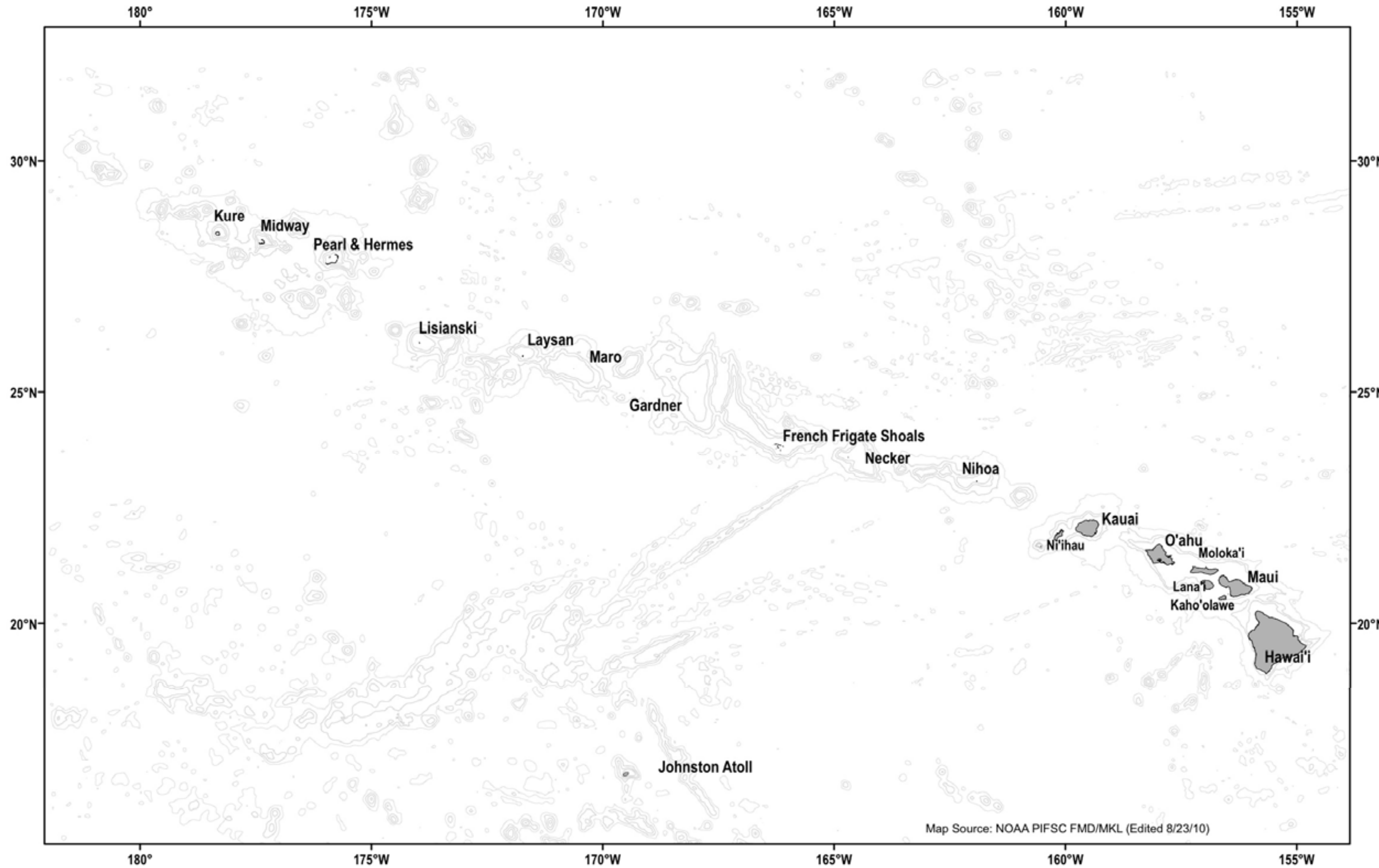
Parrish FA, Marshall GJ, Buhleier B, Antonelis GA (2008) Foraging interaction between monk seals and large predatory fish in the Northwestern Hawaiian Islands. Endangered Species Research 4: 299-308.

Schultz JK, Baker JD, Toonen RJ, Bowen BW (2009) Extremely low genetic diversity in the endangered Hawaiian monk seal (*Monachus schauinslandi*). Journal of Heredity 100:25–33.

Schultz JS, Baker JD, Toonen RJ, Harting AL, Bowen BW (In press) Range-wide genetic connectivity of the Hawaiian monk seal and implications for translocation. Conservation Biology.

This page intentionally left blank.

Figure 1. The Hawaiian Archipelago and Johnston Atoll



This page intentionally left blank.

Figure 2. Cumulative survival probability curves (l_x) for the six Northwestern Hawaiian Islands subpopulations (solid lines), based upon recent (2006-2008) rates, and all available data in the main Hawaiian Islands (dashed lines). From Baker *et al.* (in press).

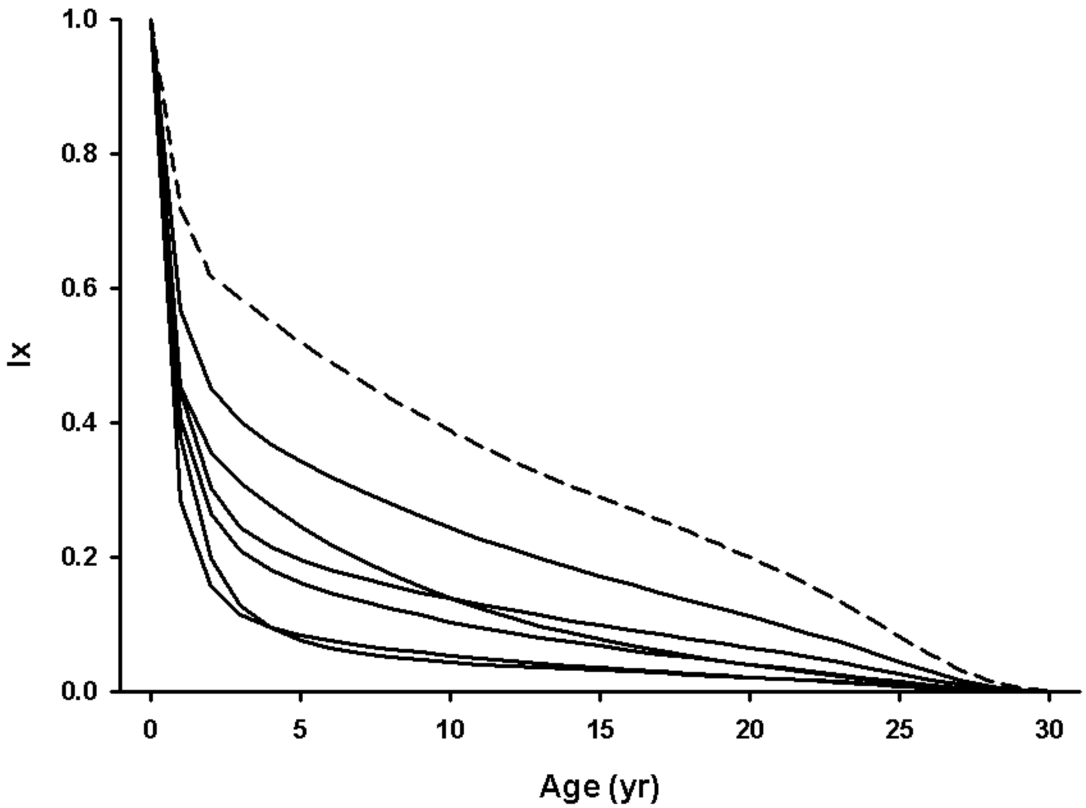


Figure 3. Fitted age-specific reproductive curves for three subpopulations of Hawaiian monk seals (LAY= Laysan Island, FFS=French Frigate Shoals, LIS=Lisianski Island).

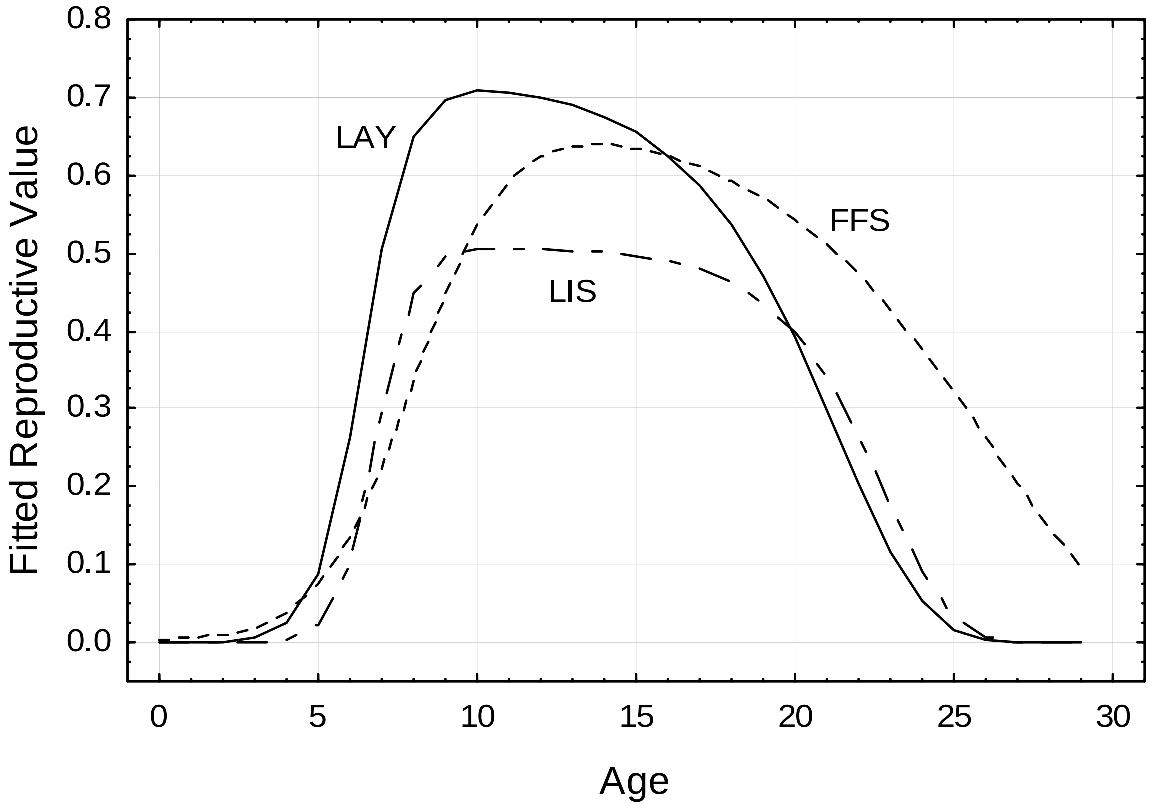


Figure 4. Simulation model projection of future Hawaiian monk seal pup production at six NWHI subpopulations pooled. Values are mean number of pups born in each simulation year in a 20-year projection.

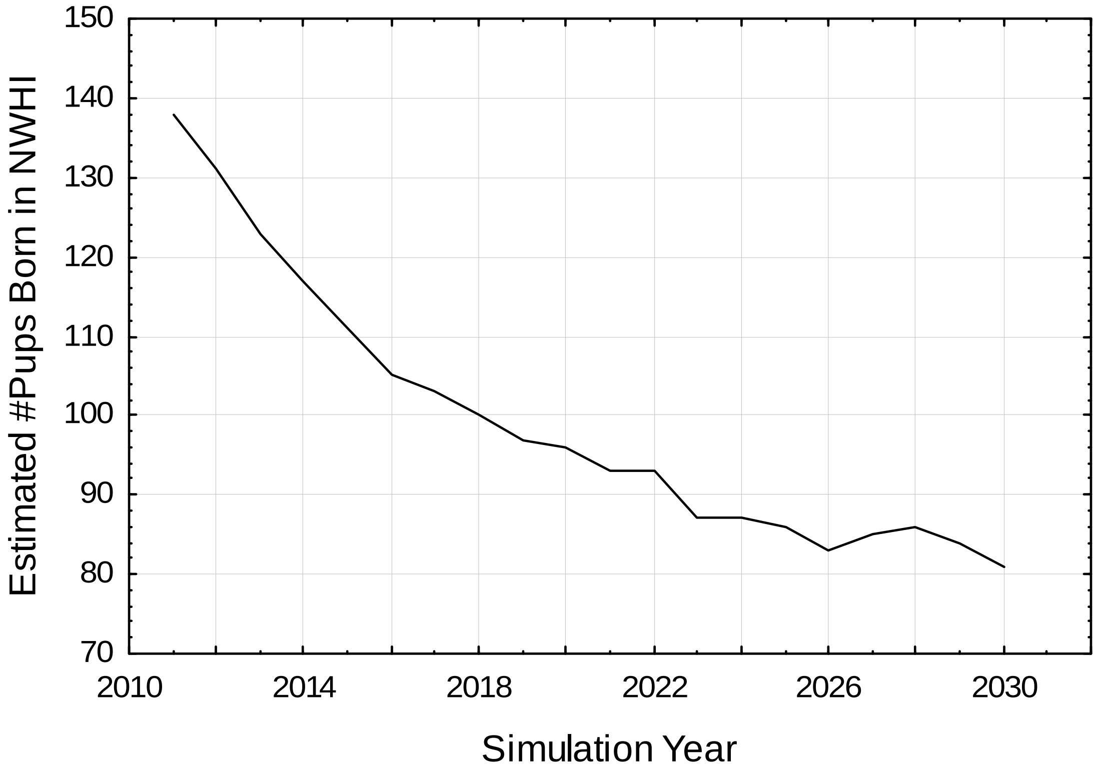


Figure 5a. Flow chart depicting decision framework for translocation of weaned Hawaiian monk seal pups.

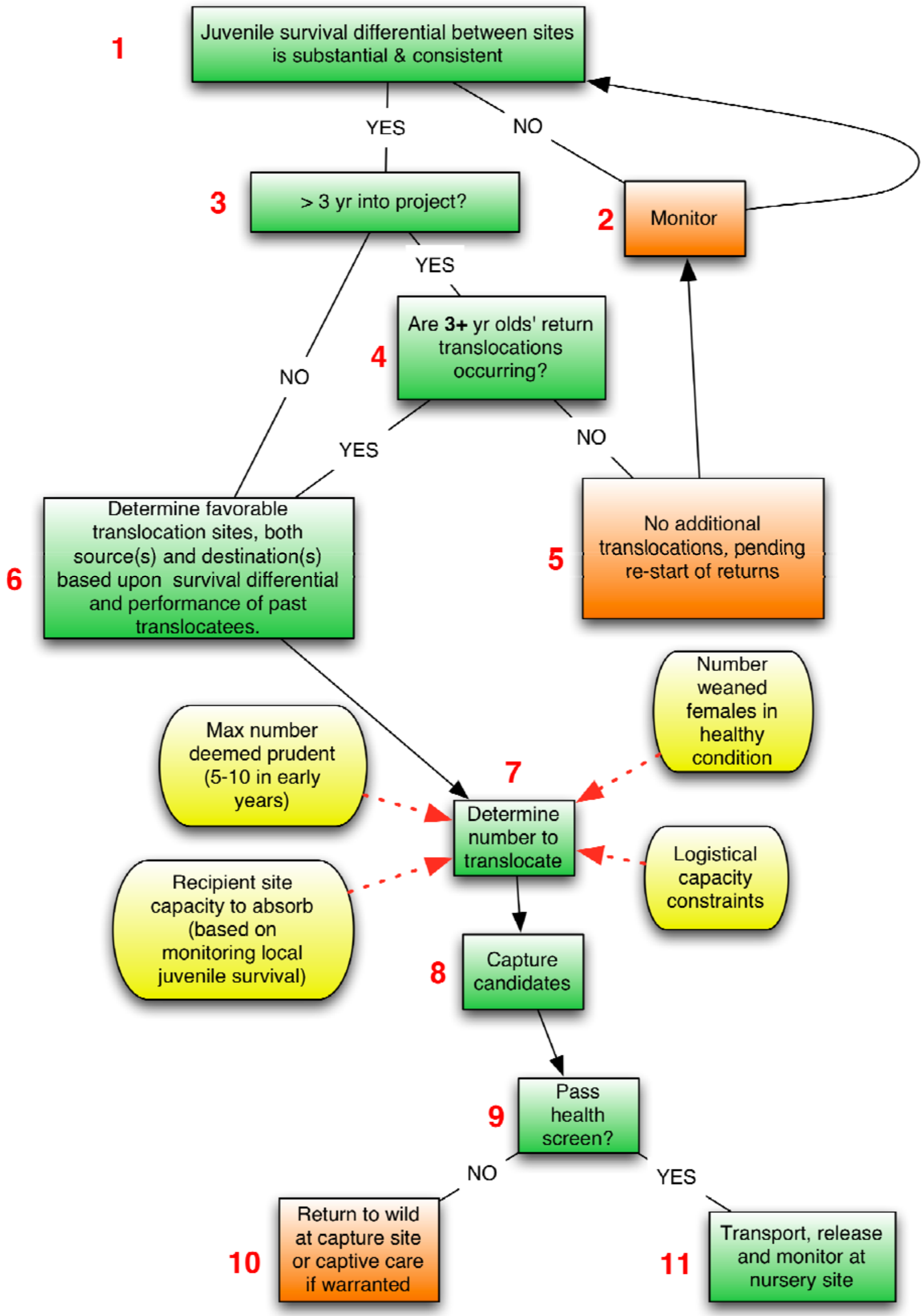


Figure 5b. Flow chart depicting decision framework for translocation of 3+ yr-old Hawaiian monk seals.

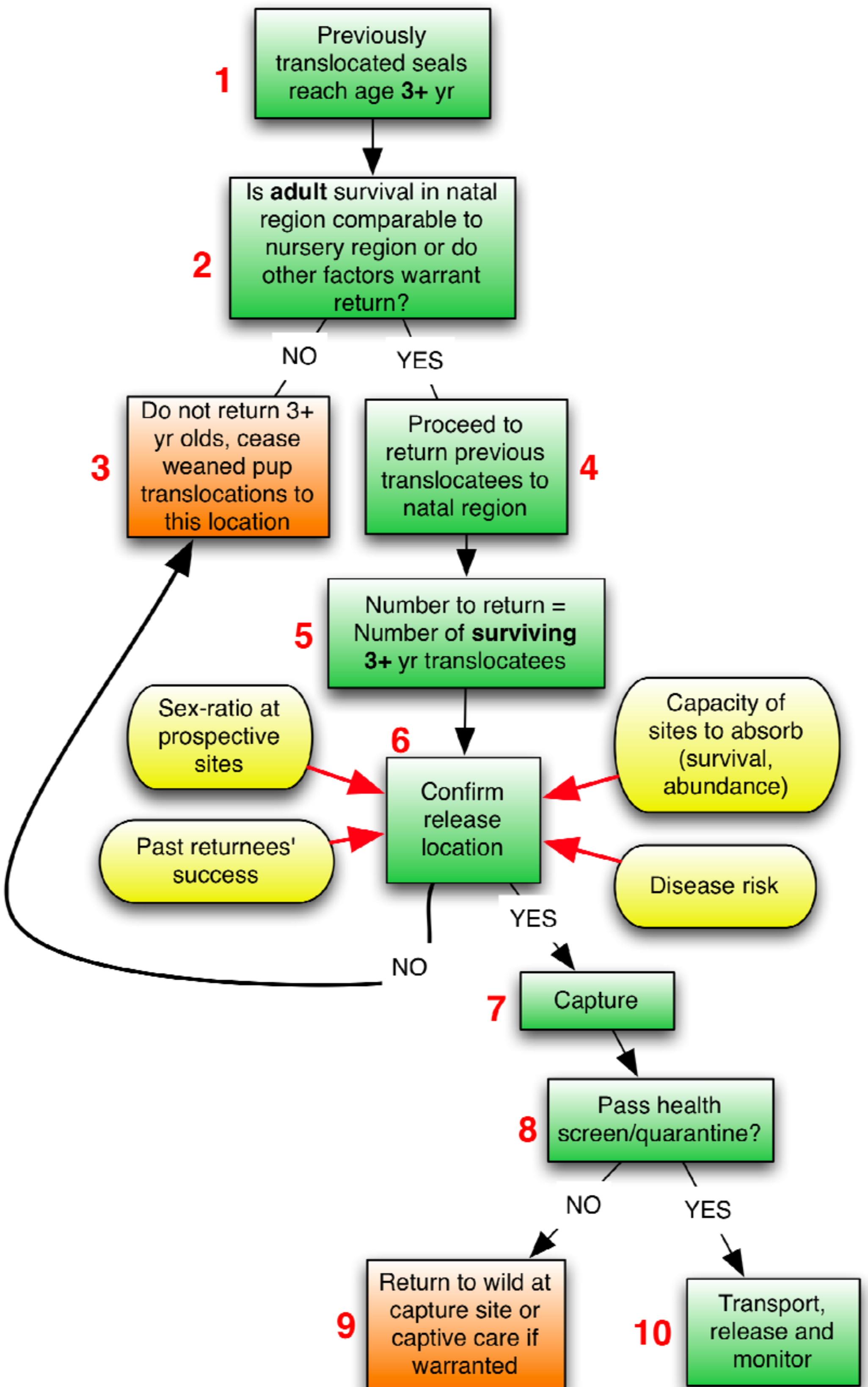


Figure 6. Contrasting age-specific reproductive value curves for French Frigate Shoals and main Hawaiian Islands MHI monk seals.

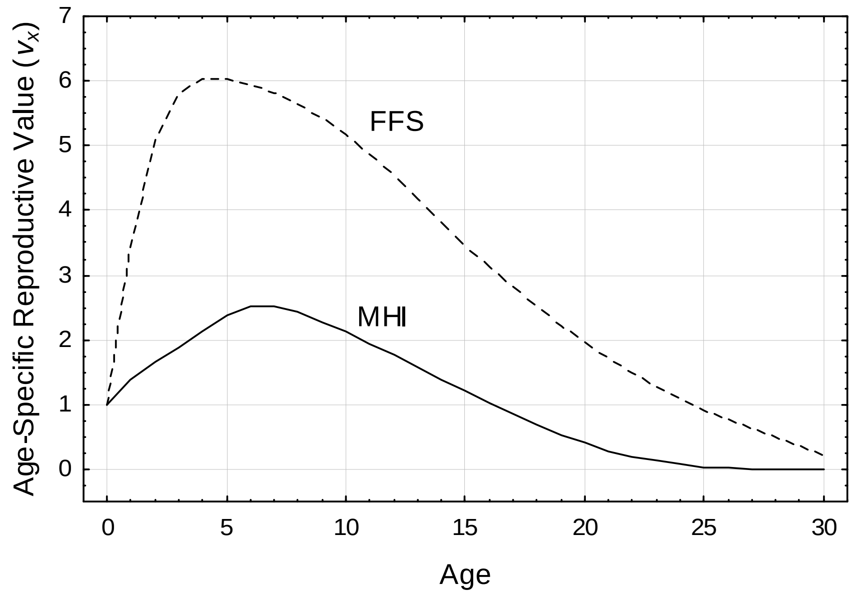


Figure 7. Age structure modification at natal site associated with a representative two-stage translocation. In this hypothetical scenario, translocated seals grow up at a nursery site and returned to the natal site at age 3, with this treatment repeated for 5 consecutive years.

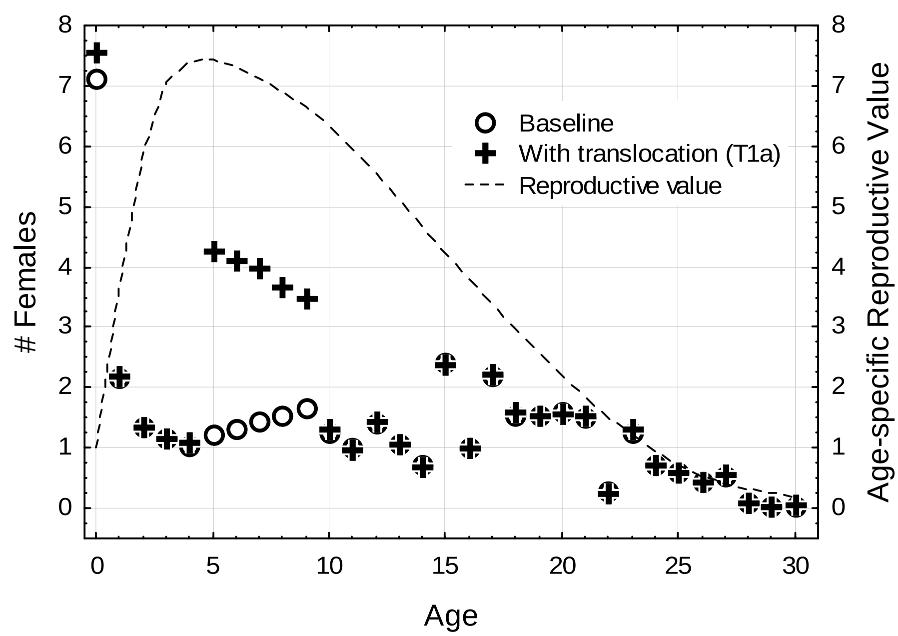
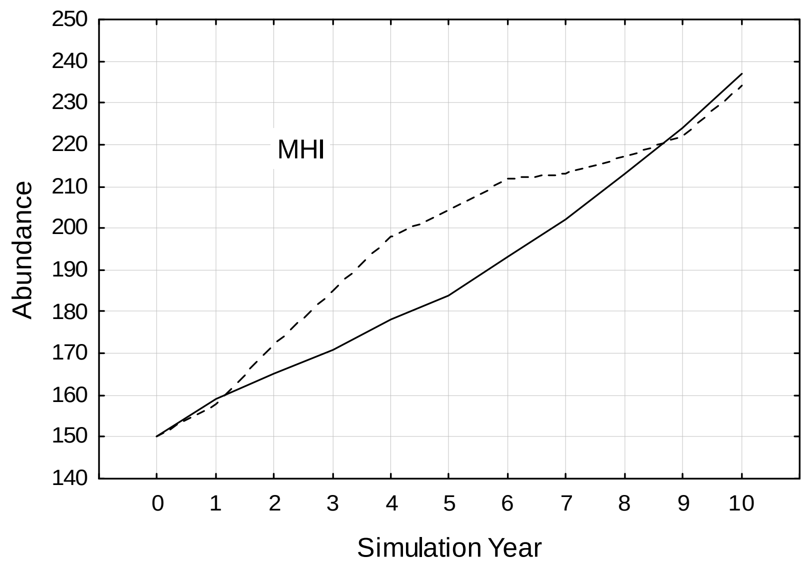


Figure 8. Simulation trajectories at the nursery (MHI) and natal (FFS) sites for a representative translocation scenario. Lines represent mean abundance at each time step, with translocation (dotted line) and without translocation (solid line). The salient difference at the nursery site is an ephemeral elevation in mean abundance during the years the project is underway.

8a. Nursery site (MHI)



8b. Natal site (FFS)

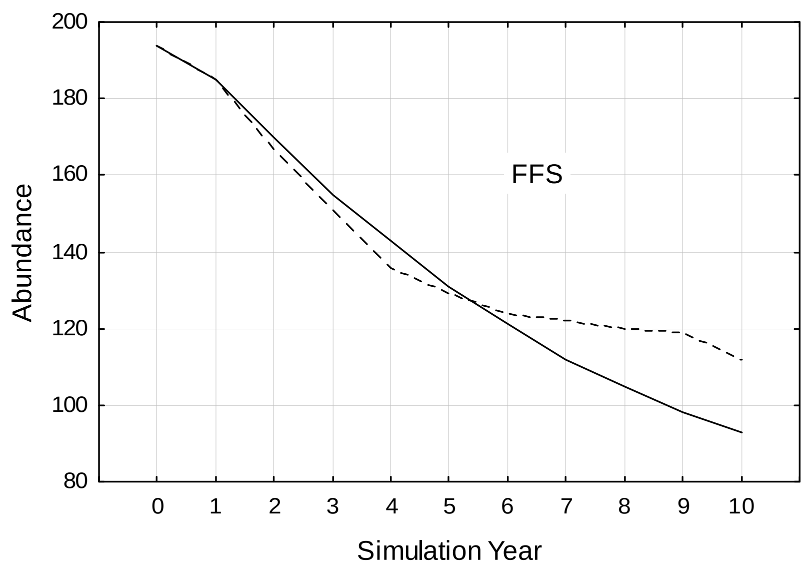


Figure 9. Mean abundance (with 5% and 95% tails) at the natal site (FFS) for the baseline (Bsl) and 8 translocation scenarios. Scenarios differ in the nursery location and survival decrements as described in Table 2.

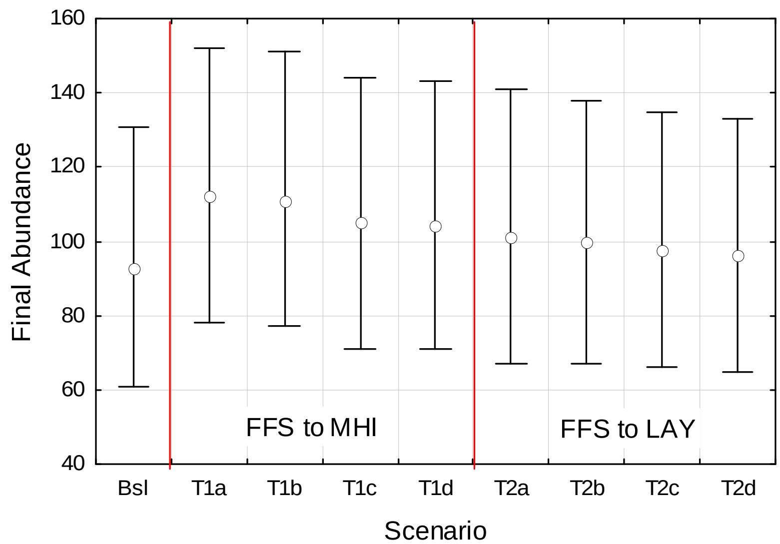


Figure 10. Population reproductive value (V_{pop} with 5% and 95% tails) at the natal site (FFS) for the baseline (Bsl) and 8 translocation scenarios. Scenarios differ in the nursery location and survival decrements as described in Table 2.

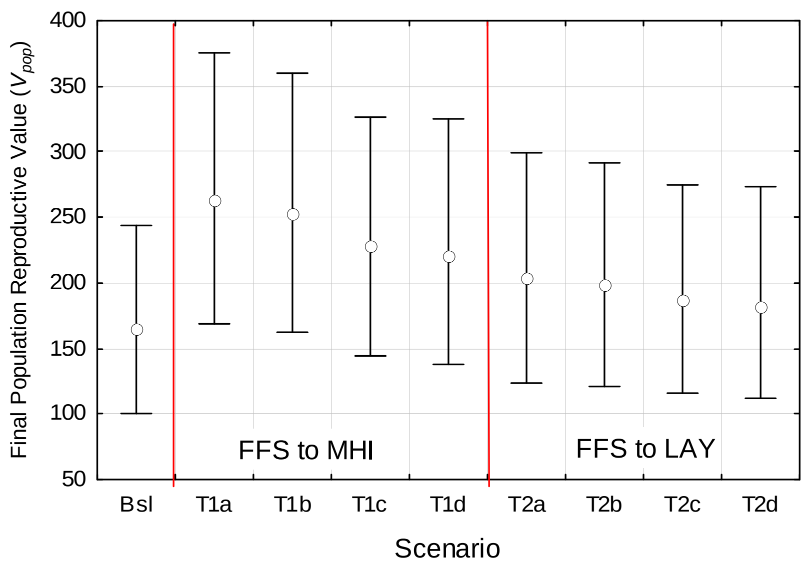


Figure 11. Change in Population Reproductive Value (ΔV_{pop}) at FFS from year 1 to year 10 of baseline and translocation simulation scenarios. Scenarios differ in the nursery location and survival decrements as described in Table 2.