Eastern Pacific Leatherback Turtle:

Ex situ Management Recommendation Development Workshop Report

On behalf of the participants of the *2021 EPLB Turtle Recommendation Development Workshop*, this document was compiled and edited by: Copsey, J. Miller, P., Ortega, A., Reina, R., Seminoff, J., Wallace, B., Williamson, S., Wyneken, J. & Shillinger, G.

English/ Spanish and Spanish/English translations provided by; Luque, J., Morales, A., Sanchez, F., Vivas, I.
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Recommended citation:
Copsey, J., Ábrego, M., Alvarez, C., Bandimere, A., Baron, J., Barragán, A., Benson, S., Cáceres, V.,Davalos, N.,Dueñas, C., Dutton, P., Flanagan, J., Gadea, V., Gray, K., Gunn, A., Hall, M., Harfush, M., Heppell, S., Herrera, D., Jimenez, A., Juarez, A., Kelez, S., Komoroske, L., Lawson, D., Lohmann, K., Mangel, J., Mast, R., Miller, D., Miller, P., Mitchell, N., Mustin, W., Ortega, A., Otterstrom, S., Plotkin, P., Quioñes, J., Ramos, S., Reina, R., Salas, C., Salazar, H., Sarti, L., Seminoff, J., Shaver, D., Steiner, T., Stewart, K., Trejo, C., Vallejo, F., Veelenturf, C., Wallace, B., Williamson, S., Wyneken, J., Zarate, P. & Shillinger, G. (2021). Eastern Pacific Leatherback Turtle: *Ex situ* Management Recommendation Development Workshop Report. IUCN SSC Conservation Planning Specialist Group, Apple Valley, MN, USA.

A digital copy of this report is available at: www.cpsg.org.

Contents

ACRONYMS AND ABBREVIATIONS

CPSG	Conservation Planning Specialist Group
EPLB	Eastern Pacific Leatherback Turtle sub-population, *Dermochelys coriacea*
IUCN	International Union for Conservation of Nature
PVA	Population Viability Analysis
SSC	Species Survival Commission (one of six Commissions within the IUCN)

PART I RECOMMENDATION DEVELOPMENT REPORT

EXECUTIVE SUMMARY

In July 2020, the Conservation Planning Specialist Group (CPSG)[1] of the International Union for Conservation of Nature (IUCN) Species Survival Commission (SSC) was enlisted by the international non-profit sea turtle conservation organization, Upwell[2], to design and facilitate a two-step decision-making process to inform conservation efforts for the Critically Endangered Eastern Pacific subpopulation[3] of the leatherback turtle *Dermochelys coriacea* (shortened to EPLB within the report). The focus of the process was to determine the extent to which *ex situ* management activities (specifically head-starting[4] and egg translocation) should be considered as complements to *in situ* efforts for the species. The process involved the participatory development of a Population Viability Analysis (PVA) model for the subpopulation, reflecting both its status and trajectory and potential future trajectories based on different conservation management interventions (both *in situ* and *ex situ*). This first phase was then followed by a second participatory planning phase, in which a wider group of stakeholders from both within and beyond the region were led through a series of meetings to develop a shared recommendation for future work. This recommendation was restricted to determining the extent to which head-starting and/or egg translocation could be used as complementary actions to augment ongoing efforts to prevent extinction of the sub-population.

The two-step process began in November 2020 and ended in February 2021. The final recommendation developed was that, given current uncertainties concerning the practicability and likely impact of *ex situ* management activities on EPLB recovery, such actions should not be embarked upon at the current time, though they merited further examination and study. A range of research themes were identified by the group that should be further investigated to help reduce uncertainties surrounding the *ex situ* management approaches proposed. This would ensure that, should ongoing *in situ* interventions be unsuccessful in slowing population decline, or an urgent need for ex situ actions be identified, *ex situ* conservation practitioners will be better equipped with the knowledge and capabilities to maximise the probability of success of additional *ex situ* measures.

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1 CPSG's mission is, *'…to save threatened species by increasing the effectiveness of conservation efforts worldwide'*. www.cpsg.org

2 Upwell's mission is, *'…to protect endangered sea turtles by reducing threats at sea, including fisheries bycatch, ship strikes, pollution, climate change and other detrimental human activities'*. www.upwell.org

3 There are seven genetically-distinct subpopulations of this species globally (IUCN Red List (Wallace et al 2013). The Eastern Pacific subpopulation spans from the Gulf of California to Argentina, though nesting is concentrated in Mexico and Costa Rica.

4 Head-starting is considered here to be the incubation and hatching of wild-harvested eggs and raising of subsequent hatchling turtles *ex situ* prior to release back to the wild.

FINAL RECOMMENDATION STATEMENT

Context

In January and February 2021, a group featuring leatherback researchers, fisheries biologists, sea turtle conservation practitioners, students, and supporters (see stakeholder participation section for more details) assembled virtually to participate in the *Ex Situ* Leatherback Conservation Workshop. This workshop consisted of eight 3-hour online Zoom sessions and the participants were provided background and context about the plight of the Eastern Pacific leatherback turtle (hereafter, EPLB). The group also was presented with key elements of the organizers' previously completed Population Viability Analysis (PVA; see Part II) as well as the projected population-level responses to various *ex situ* options, in concert with variable levels of conservation effort *in situ*, namely bycatch mitigation. Throughout these discussions, participants were asked to share ideas and opinions relating to the viability of *ex situ* conservation efforts for the recovery of the EPLB. Through this dialogue, it was clear that all participants shared a common goal of recovering the EPLB, although there were differing opinions on how to best achieve such success.

Recommendation(s)

The main threats to EPLB persistence include impacts at nesting beaches and bycatch of older life stages in artisanal and industrial fisheries. Acknowledging that these threats will continue unabated without ongoing nesting beach protection and bycatch reduction, we recommend that *in situ* measures be strengthened and expanded to the maximum extent possible.

Given the uncertainties of the practicability of *ex situ* management techniques, as well as the effectiveness of these actions for EPLB recovery, we recommend that *ex situ* efforts involving translocation between nesting beaches or head-starting are not conducted at this time. Instead, we urge that, before *ex situ* actions are considered and implemented, studies are conducted to fill key knowledge gaps about the biology and ecology of this population, as well as to confirm/update important demographic assumptions that were made as part of the PVA process. While these studies [**see research themes section**] may not be directly focused on *ex situ* conservation *per se*, the results would be instructive for prioritizing *ex situ* actions if or when such efforts are pursued.

Considering the challenges of egg translocation and hatchling rearing, we also recommend that leatherback husbandry practices continue to be refined. This may be achieved via egg translocation trials, the development of novel husbandry infrastructure that promotes the survival of leatherback post-hatchlings in captivity, including captive study of live turtles to fill knowledge gaps related to poorly-understood life stages.

Justification

Our recommendation to promote and expand *in situ* conservation efforts result from knowledge that, if implemented correctly, such efforts—while not without uncertainties—likely provide the best opportunity for population recovery. We consider it critical to involve fishers, other relevant livelihood groups and communities in this process, training them or working with them directly.

Our recommendation to forego *ex situ* measures at this time results from the uncertainties associated with population projections based on PVA models, as well as a lack of understanding about key biological traits such as the extent to which leatherback navigational abilities are learned vs.

inherited, the timing of natal imprinting that underpins nest site philopatry, as well as basic data gaps in their husbandry. Our recommendation also recognises that certain concerns remain to be addressed, including socio-political, economic or other human-centred factors that should be considered in any decision made to proceed with *ex situ* management.

Our recommendations to conduct biological studies and to refine translocation and husbandry practices is given so that, if Eastern Pacific leatherbacks continue to decline despite enhanced *in situ* efforts and if *ex situ* conservation measures are deemed necessary and practicable, then conservation practitioners will be equipped with the biological information and husbandry capabilities that will improve the probability of success for *ex situ* measures.

Desired Outcome

Ultimately, the goal of our efforts is to recover the Eastern Pacific leatherback turtle subpopulation and restore their ecological roles in the Pacific Ocean. We hope that recovery is possible through ongoing and enhanced *in situ* conservation efforts; however, if this is not effective, we want to position the leatherback conservation community to be as successful as possible with conservation efforts that may occur in addition to *in situ* efforts.

REQUIRED RESEARCH THEMES

To reduce high levels of uncertainty regarding the implementation of any future *ex situ* management interventions, and to fill important knowledge gaps in the biology, ecology and behaviour of the species more broadly, a suite of research themes and questions were identified for investigation during the workshop. These themes and questions are not meant to reflect the full range of research needs for the species. The answers to many of these questions will be useful for testing assumptions made in determining the parameters and inputs in the PVA and could be incorporated in an iterative process. This should refine predictions of the PVA modelling on the benefit or otherwise of different elements of *ex situ* interventions. The original notes which generated this set of research themes are detailed in **Appendix I** and **Appendix II**.

Theme summaries:

1. *Life history and vital rates (including survival, growth and reproduction)*

   These are needed for models to evaluate the potential benefits of different conservation strategies. Some rates are reasonably well known but may vary with environmental conditions and need to be monitored, such as remigration interval (i.e., number of years between two consecutive nesting seasons for the same female turtle) which will determine reproductive output over any given timeframe. Age at maturation is still in question and has a large impact on model outputs. These rates can vary between populations of leatherback turtles and whether this variation is due to environmental or genetic variation would be important to consider prior to any translocations between populations.

2. *Health, husbandry and head-starting*

   Research questions in this theme generally focus on understanding the effects of incubation and captive rearing on leatherback hatchlings compared with naturally-incubated hatchlings. Determining the survival, health, microbiome, and husbandry protocols for incubating eggs and raising hatchlings are identified as important for improving the developmental outcome in an *ex situ* environment. The net impact of head-starting on population persistence will largely be determined by the answer to these questions and those in the 'Dispersal and early survival' theme below.

3. *Development and sex ratios*

   Understanding processes that determine developmental success and failure, and the methods of incubation to improve them are the main goals within this theme. The impact of incubation conditions on sex ratios and their ultimate impact on reproductive capacity of the population is also identified as a research priority.

4. *Early life stage translocation practices*

   The possibility of translocating eggs or hatchlings among populations raises questions regarding imprinting of geomagnetic location and its impact on navigation and migration of translocated animals. Other questions address knowledge gaps about the effects of translocation on developmental success and the protocols for moving eggs short and long distances. A key question to be addressed is whether there exists a subpopulation which could sustain 'harvesting' of eggs for any potential translocation strategy.

5. *Dispersal and early survival*

   Uncertainties about natural and head-started hatchling survival rates and dispersal patterns were the main knowledge gaps identified. Understanding predation risk, the effect of hatchling size on survival during dispersal and the capacity of translocated animals to find foraging habitats require investigation.

6. *Genetics*

   This theme identified that genetic diversity and the effect of mixing genetic stocks from different populations needs to be understood to determine whether *ex situ* actions will be viable. The possible impact on the genetic diversity of source populations resulting from removal of eggs or hatchlings for translocation is unknown but may be significant. Similarly, the genetic effects of the introduction of animals from source populations of different genetic stock to recipient populations is not yet understood and its impact may be different when donor and recipient populations are spatially closer compared with when they are distant. Specifically, sources within the Eastern Pacific are genetically closer related, compared with Atlantic sources which have estimated divergence times from the Pacific population(s) at a median of 170,000 YA (CI 0.6-0.35 MYA; Duchene et al. 2012).

7. *Socio-politics and public engagement*

   Identifying and engaging in-country or in-region scientific and veterinary expertise in *ex situ* management will be important for support and success. Understanding the social and political perspectives, values, and concerns towards sea turtles and their conservation (in particular *ex situ*) is important to determine likely aids and barriers that might exist. This may lead to the design of one or more approaches for socially introducing *ex situ* management concepts and practice to local communities and government agencies. Identifying what strategies would engage communities, governments and potential funders without impacting *in situ* conservation efforts is a major knowledge gap. There is also a need to determine opportunities for community outreach and local job creation through *ex situ* management.

8. *Potential climate change impacts*

   Climate change will impact both the land and sea- based life stages. These effects likely will include changes in ocean current speeds, drift directions, eddy formations and other factors may play a major role in the oceanic development, dispersal and survival of hatchlings and juveniles. Climate change may also significantly alter hatchling sex-ratios, hatching success and hatchling fitness of naturally incubating nests. Therefore, research on these potential changes should be a high priority, which would allow us to anticipate problems associated with climate change that could potentially nullify efforts to produce more hatchlings by any conservation program or strategy.

POST-WORKSHOP STEPS

Related to priority research development

1. Prioritise different research themes and questions for their feasibility and impact on *ex situ* conservation actions.
2. Undertake survey of workshop participants to identify individuals/ groups who would be willing to commit to developing one or more of the proposed areas of research to fill key knowledge gaps.
3. Formal publication of these questions relevant to *ex situ* management as a contribution to broader sea turtle conservation research, like the *'Global research priorities for sea turtles'* in Endangered Species Research in 2010 (Hamann et al. 2010).
4. Determine process for iteration of PVA modelling using results of research questions.
5. Identify costs of different research questions and funding required to undertake them.
6. Consider potential sources of funding and assess their impact on existing conservation work.

Related to communicating the results of this report

1. Once all workshop participants have had the opportunity to comment on this report, the final version will be shared with the following groups (though not necessarily restricted to these groups):
    a. Laud OPO Network
    b. IUCN Marine Turtle Specialist Group
    c. Costa Rican, Mexican, Nicaraguan, Panamanian, Colombian, and US government officials (e.g., Ministry of Environment- MINAE- in Costa Rica)
    d. Upwell funders
    e. Wider sea turtle research and conservation community.
2. Also consider making the report accessible to the following:
    a. Global Environment Facility (World Bank)
    b. Other UN implementing agencies (UNDP, UNEP, UNESCO)
    c. Regional fisheries management organizations (RFMOs)
    d. Potential research partners
    e. Make publicly available e.g., through ResearchGate, relevant list-serves (e.g. c-turtle list, Laud OPO list), and included within CPSG documents library
3. If the wider action plan for the species is to be revisited later this year, then a decision should be made as to how to integrate the results of this workshop with that planning process.
4. There is also the opportunity to include the report within multiple publications, linked to the PVA.

Workshop process

WORKSHOP OVERVIEW

In February 2020, the Conservation Planning Specialist Group (CPSG; www.cpsg.org) of the IUCN Species Survival Commission was approached by the Monterey, California based marine turtle conservation organisation *Upwell* (https://www.upwell.org/), whose mission is to protect endangered sea turtles by reducing threats at sea, including fisheries bycatch, ship strikes, pollution, climate change and other detrimental human activities. The request was to design and facilitate a stakeholder-inclusive process to critically assess the possible added value that incorporating one or both proposed actions (head-starting and/or egg translocations) into ongoing *in situ* efforts could contribute to alleviating the imminent risk of extinction for this species in its last nesting strongholds within the region, primarily in Costa Rica and Mexico.

In July 2020, CPSG was commissioned to undertake the following two-step participatory process:

1) To work with Upwell, marine turtle researchers and other related experts from both beyond and within the region (including participation from the Laúd OPO Network) to undertake a Population Viability Analysis (PVA) which would generate both a baseline model for the subpopulation and additional models to predict the likely added value of implementing one or both *ex situ* conservation interventions proposed- head-starting and egg translocation- in addition to ongoing *in situ* actions, including bycatch mitigation and nest site protection work;
2) To work with a wider suite of stakeholders to use the results of the PVA analysis and develop one or more recommendations as to the extent to which some form of *ex situ* management could complement *in situ* efforts in contributing to the stabilisation and subsequent recovery of the species in the region.

Details of the PVA analysis are provided in Part II of this report. In Part I of this document, we focus on the process and the product of the second step in the process, to develop recommendations for future conservation action, with a particular focus on possible *ex situ* work.

SPECIES CONSERVATION STATUS

Globally, the leatherback turtle *Dermochelys coriacea* is classified as Vulnerable by the IUCN (Wallace et al. 2013), although population trends for each of the seven regional subpopulations of the species vary in size, range and status. The Eastern Pacific subpopulation of the species (EPLB) is one distinct regional management unit (RMU), nesting along the East coast of Central and South America, from Mexico to Ecuador and migrating south to the Eastern Pacific Ocean off the coast of Ecuador, Peru and Chile (Shillinger et al. 2008; Bailey et al. 2012; Laúd OPO Network 2013). In recent decades, the EPLB subpopulation has experienced a precipitous decline in abundance. Primary nesting beaches are restricted to three states in Mexico and one province in Costa Rica. Annual nesting turtle counts indicate a population decline of more than 90% since the 1980s (Network 2020), qualifying the subpopulation as Critically Endangered according to IUCN criteria.

Threats to the species include previously high levels of egg consumption by humans from the nesting beaches and climate change, though the primary current acute threat to the species appears to be incidental capture (bycatch) by fisheries. While significant progress has been made in minimising human egg consumption through nesting beach protection and public engagement, the subpopulation is predicted to be functionally extinct by 2080 (Network 2020). The results of the current PVA model indicate a high probability (>90%) of the Costa Rica subpopulation becoming extirpated within 45 years, and the Mexico subpopulation – as well as the combined metapopulation – becoming extirpated within 55 years (Miller

2021). The model also indicates that bycatch mortality mitigation of at least a 30% reduction in the current rate would be required to achieve sustained population growth in Mexico; while within Costa Rica, a 40% reduction in bycatch mortality would enable the mean nesting female abundance to reach 68% of its original value within 60 years (Miller 2021).

In 2013, the Eastern Pacific Leatherback Conservation Network (or Laúd OPO Network) developed a strategy to counter threats to the species, specifically through implementation of measures to reduce bycatch and increase nesting productivity (Laúd OPO Network 2013). Whilst ongoing implementation of this strategy is vital, additional complementary actions have been proposed to avert extirpation of the EPLB subpopulation and to develop the capacity to repopulate the RMU, should it become necessary.

These actions include the following, which were the focus of the workshop:

1. Translocation of eggs from other subpopulations; and
2. Captive rearing and release of juvenile turtles into the Eastern Pacific (i.e., ‘head-starting’).

PROCESS DEVELOPMENT

Given the Covid-19 pandemic, it was not possible to convene an in-person regional, participatory workshop as had originally been planned. Instead, a virtual process was designed, involving stakeholders being brought together electronically to discuss the results of the PVA and the implications in terms of recommendation development.

A modified ‘Structured Decision-Making’ process (Gregory et al. 2012) was developed to provide a structure to the participatory meetings (**Figure 1-1.**).

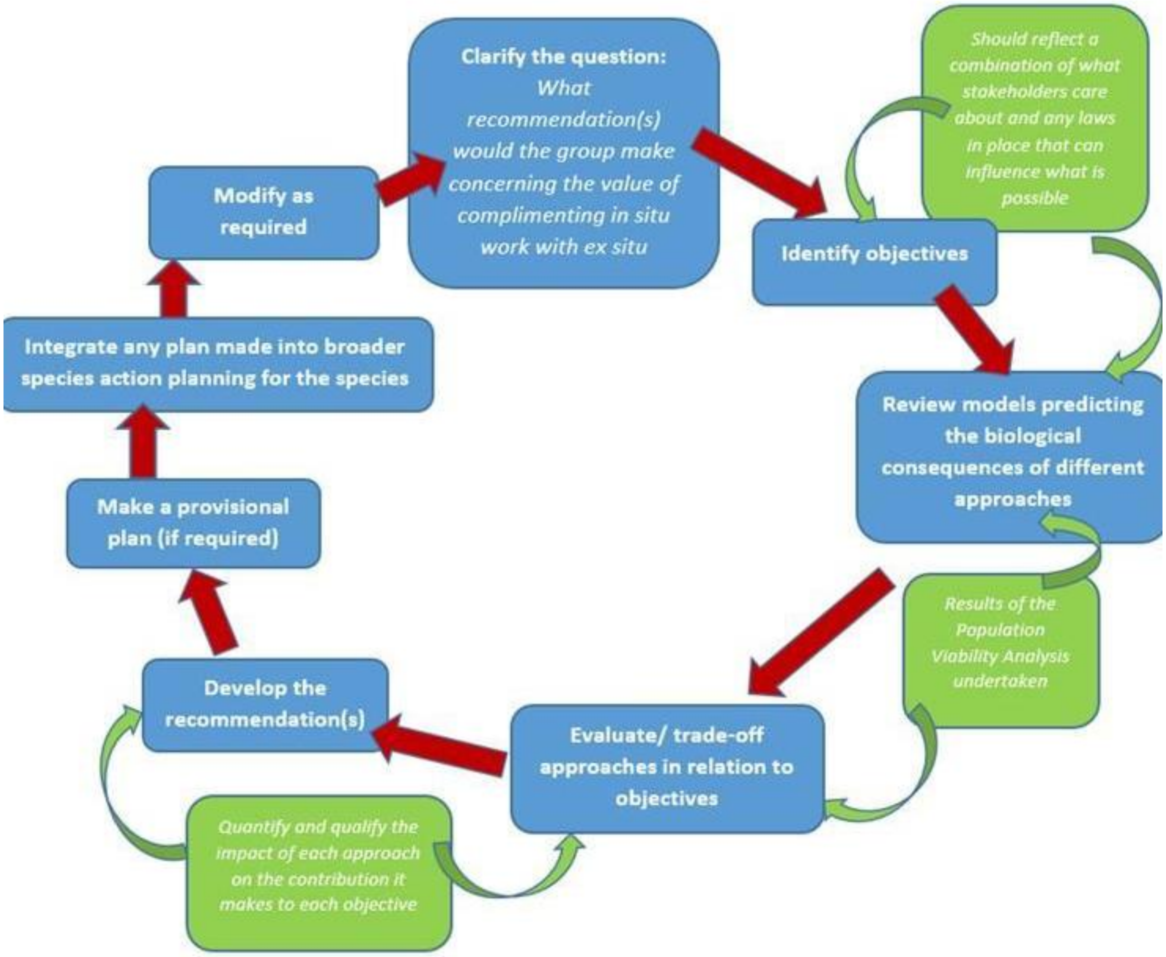

Figure 1-1. Summary process for the development of workshop recommendations.

The process was coordinated over a series of eight 2-3 hour virtual meetings, beginning January 18th and ending on the 8th of February 2021. **Table 1-1.** Outlines the topics covered during each of the meetings.

Date (duration in hours)	Focus	Outline
Monday 18th January (2hrs)	To provide an overview of the PVA process and to introduce the structure of the meetings to follow.	As additional stakeholders joined the group for this process who had not been involved in the development of the PVA models, this meeting was scheduled to ensure all stakeholders were familiar with the PVA process itself, and with how the baseline model was developed.
Tuesday 19th January (3hrs)	To begin the process of developing stakeholder objectives.	The meeting was devoted to collating what stakeholders cared most about when considering developing any recommendation based on the relative added value of incorporating *ex situ* conservation measures into existing *in situ* work.
Wednesday 20th January (3hrs)	To present the results of the PVA models of conservation interventions.	In this meeting the focus was on presenting and discussing the series of PVA models developed that predicted the likely impact of different combinations of conservation interventions on the status of the subpopulation over a 60 year timeframe.
Monday 25th January (3hrs)	To finalise fundamental objectives.	In this meeting stakeholders continued to work on their concerns and produced a set of fundamental objectives that they cared most about satisfying.
Thursday 28th January (3hrs)	Exploring uncertainties and knowledge gaps.	This meeting was devoted to critically reviewing some of the assumptions made within the PVA models and to identifying the most significant uncertainties and knowledge gaps relevant to the conservation of the species.
Tuesday 2nd February (3hrs)	Evaluating alternatives.	Following presentations on the knowledge gaps and uncertainties relevant to both *ex situ* and *in situ* work, further discussion was held to critically review what is known about the likely success of work in both domains.
Thursday 4th February (3hrs)	Evaluating alternatives (continued).	The *ex situ* management alternatives being considered were discussed in greater depth helped by presentations on the practical implications (including likely cost) of their implementation.
Monday 8th February (3hrs)	Developing recommendations.	Based on the prior analysis, stakeholders worked to identify if there was a collective recommendation that could be developed coming from the review of alternative proposed *ex situ* actions. The draft recommendation statement outlined was subsequently drafted by one of the workshop participants for circulation to all following this meeting. The final recommendation statement was then developed remotely by stakeholders.

Table 1-1. Outline of virtual meeting content.

WORKSHOP PARTICIPANTS

Seventy-two participants were invited to the workshop, with 51 individuals (71%) attending at least one of the eight online sessions and an average of 36 participants attending each one (**Table 1-2**). Stakeholders present represented both the Laúd OPO Network and a wider suite of turtle experts from the Cayman Islands, Australia, the United Kingdom and North America. Representation from across the population range was achieved and included participants from Mexico, El Salvador, Nicaragua, Costa Rica, Panama, Colombia, Ecuador, Peru, and Chile. Both government and non-government groups were represented. In addition to the group that participated in the virtual workshop process, Dr. Philippe Gaspar (Volunteer senior scientist, Mercator-Ocean, France, and a co-creator of the Sea Turtle Active Movement Model (STAMM)) provided input to address some of the questions raised during the process, and to address certain assumptions.

Online Meeting Attendees	Session 0	Session 1	Session 2	Session 3	Session 4	Session 5	Session 6	Session 7	Total Sessions Attended
Jamie Copsey	X	X	X	X	X	X	X	X	8
Phil Miller	X	X	X	X	X	X	X	X	8
Andrea Morales	X	X	X	X	X	X	X	X	8
Francy Forero-Sanchez	X	X	X	X	X	X	X	X	8
Ilad Vivas	X	X	X	X	X	X	X	X	8
José A. Díaz-Luque	X	X	X	X	X	X	X	X	8
Alison Gunn	X		X						2
Ana Barragán	X	X	X	X	X	X		X	7
Anna Ortega	X	X	X	X	X	X	X	X	8
Arturo Juarez	X	X	X	X	X		X	X	7
Ashleigh Bandimere		X		X	X			X	4
Astrid Jimenez	X	X							2
Brian Stacy	X	X	X	X	X	X	X	X	8
Bryan Wallace		X	X	X	X	X	X	X	7
Callie Veelenturf				X	X		X	X	4
Carlos Delgado-Trejo	X	X	X	X	X	X	X	X	8
Carlos Salas			X	X	X	X		X	5
Clara Ortiz-Alvarez	X		X						2
Celina Dueñas				X			X		2
Daisy Herrera		X	X	X		X	X		5
Deb Miller	X	X	X	X	X	X	X	X	8
Donna Shaver				X	X		X	X	4
Dwight Lawson	X	X		X	X	X	X	X	7
Felipe Vallejo			X	X			X		3
George Shillinger	X	X	X	X	X	X	X	X	8
Heydi Salazar	X			X	X	X	X		5

Online Meeting Attendees	Session 0	Session 1	Session 2	Session 3	Session 4	Session 5	Session 6	Session 7	Total Sessions Attended
Jeanette Wyneken	X	X	X	X	X	X	X	X	8
Javier Quiofies	X		X	X	X				4
Jeff Mangel	X	X	X	X	X	X	X	X	8
Jeff Seminoff		X	X	X	X	X	X	X	7
Joe Flanagan	X	X	X	X	X	X	X	X	8
Juan Manuel Rguez-Baron		X		X	X	X	X	X	6
Kelly Stewart	X								1
Ken Lohmann	X	X	X	X	X	X	X	X	8
Kim Gray	X	X	X	X	X	X			6
Laura Sarti	X	X	X	X	X	X	X	X	8
Lisa Komoroske	X	X	X	X	X	X		X	7
Marino Ábrego			X	X	X	X	X		5
Martha Harfush		X	X	X	X	X	X	X	7
Martin Hall		X	X	X	X	X		X	6
Nestor Davalos		X	X	X	X			X	5
Nicki Mitchell			X		X	X	X		4
Pamela Plotkin	X	X	X	X	X	X	X	X	8
Patricia Zarate	X	X	X	X	X	X	X	X	8
Peter Dutton							X		1
Richard Reina	X	X	X		X	X	X	X	7
Rod Mast		X				X	X		3
Sarah Otterstrom	X	X	X	X	X	X	X	X	8
Scott Benson	X	X	X	X	X	X			6
Sean Williamson	X	X	X	X	X	X	X	X	8
Selina Heppell	X	X		X	X		X		5
Shaleyla Kelez	X	X	X		X	X	X		6
Susan Ramos	X	X	X						3
Todd Steiner		X	X		X	X	X	X	6
Velkiss Gadea	X	X			X	X			4
Verónica Cáceres								X	1
Walter Mustin	X	X	X	X	X	X	X	X	8
Total each session	**38**	**43**	**43**	**44**	**46**	**41**	**41**	**38**	
Total excluding facilitators	**32**	**37**	**37**	**38**	**40**	**35**	**35**	**32**	

Table 1-2. Stakeholders participating in each of the eight meetings (workshop facilitators identified with red lettering).

IDENTIFYING FUNDAMENTAL OBJECTIVES

The central question to be responded to during this process was as follows:

What recommendation(s) would the group make concerning whether ex situ actions could provide significant benefit to the conservation of the EPLB?

The response to this question would consider the shared understanding and values of the group alongside the results of the PVA process. The first step in answering this question involved identifying what stakeholders cared most about achieving (or avoiding) in developing any recommendations.

A range of concerns were raised by stakeholders, including a desire for any recommendation to contribute to maximising the EPLB population size over the long-term, through to concern over the potential negative impact on source populations of removing eggs for egg translocation and how such interventions might be perceived politically and by local communities. Concern was raised over the possible genetic impacts of introducing turtle eggs from other subpopulations, as was finding ways to minimise levels of uncertainty in any actions proposed.

Six fundamental objectives were identified that stakeholders wanted to ensure would be achieved through any recommendations made (**Table 1-3.**)

Fundamental objectives resulting from stakeholder discussions
To maximise the number of turtles out in the wild, long-term.
To avoid negative impacts on existing wild populations.
To maximise the sustainability of financial funding to the wider project (in particular *in situ* efforts).
To maximise political support for the conservation work.
To achieve social benefits and public buy-in for this conservation work.
To maximise the health and survivorship of young managed *ex situ.*

Table 1-3. Fundamental objectives for stakeholders in developing recommendations.

With these fundamental objectives in mind, stakeholders reviewed the results of the PVA modelling of scenarios.

EXECUTIVE SUMMARY OF THE POPULATION VIABILITY ANALYSIS (PVA)

PVA is a valuable process for assembling key demographic and ecological data on the species or population of interest, for projecting the likely fate of that species or population at some time in the future under current management conditions, and for predicting the relative efficacy of alternative management scenarios to increase the future likelihood of population growth and persistence. The computer simulation software known as Vortex (Version 10.4) was used to construct the model. Vortex is a stochastic simulation, in which 1000 iterations of each model scenario are conducted to assess the likely future state of a population whose growth or decline is governed by annual environmentally-driven variation in mean breeding and mortality rates.

The Vortex model treated each set of national beaches (in Costa Rica and Mexico) as separate components of the Eastern Pacific metapopulation. This allowed for an estimation of future population performance at a fine spatial scale, thereby facilitating a more complete understanding of the prospects for local population recovery under alternative management scenarios. The present analysis considered four ex situ management options: head-starting eggs collected from natural nests in Mexico or Costa Rica, and transferring them to a nearby rearing facility for incubation and rearing to three months before releasing them offshore; translocating eggs from an unidentified external source and re-locating them in artificial nests on existing turtle nesting beaches in Costa Rica and Mexico to incubate and hatch under natural conditions; hatching externally-sourced, translocated eggs within an incubation facility and releasing them at a near shore location 24-48 hours after hatching; and hatching and reading to three months of age externally-sourced, translocated eggs before releasing at an offshore location.

If we assume that management activities in place today do not change in the future, the model predicted that both the Mexico and Costa Rica subpopulations would continue to decline at the current rate of approximately 15% per year. These results are in line with those of the previous Laúd OPO Network analysis (Network 2020), indicating a high level of agreement in the predictions made by the two models. The expected number of nesting females in Costa Rica was likely to drop to less than five individuals within approximately 12 years from the start of the analysis (i.e., the year 2032), while the number in the Mexico subpopulation was likely to decline to similar levels in about 25 years (i.e., the year 2045). Model results indicated a high probability (>90%) of the Costa Rica subpopulation becoming extirpated in less than 45 years, and the Mexico subpopulation – as well as the combined metapopulation – becoming extirpated in less than 55 years. Across those model iterations in which extinction occurred (i.e., abundance declines to zero or only one sex remains), the mean time to extinction was just 31 years for Costa Rica and 42 years for Mexico. These results demonstrate the higher risk of local nesting population extirpation.

Reducing subadult and adult leatherback mortality through mitigating fisheries bycatch interactions arrested the rate of subpopulation decline in both Mexico and Costa Rica, but rather aggressive mitigation appeared to be necessary to facilitate sustained increases in nesting female abundance. Sustained subpopulation growth in the Mexico subpopulation was achieved when the extent of bycatch mortality mitigation reached 30% (i.e., when the annual subadult and adult mortality rate is proportionally reduced by 30%). Note, however, that this threshold target of bycatch mortality mitigation was successful only at bringing the mean nesting female abundance among Mexico beaches back up to its initial value of 54 individuals after 60 years of the simulation. Higher levels of bycatch mitigation (i.e., 40% reduction) led to comparatively substantial subpopulation growth, with nearly 180 nesting females in this subpopulation at year 60. In stark contrast to the predictions for Mexico, the Costa Rica subpopulation failed to return to the initial abundance of nesting females even with the most aggressive level of bycatch mortality mitigation tested here. The scenario featuring 40% bycatch mortality mitigation resulted in a final mean nesting female abundance of 10.9 individuals, just 68% of the original value of 16 nesting females.

Further sensitivity analysis of the model indicated that if survival of head-started individuals is only marginally improved compared to wild-born turtles, a dedicated head-starting effort was unlikely to provide meaningful benefit if conducted parallel to additional *in situ* management activities. Moreover, if released individuals are not as robust as their wild counterparts, and consequently suffer higher rates of mortality in their new wild environment, a head-starting program would be detrimental to the subpopulation to which that management activity is applied. In light of this analysis and associated discussions that were conducted as part of this larger project, it is recommended that any proposal to initiate a head-starting program would be preceded by extensive research and experimental trials to better understand the relative survival of hatchling leatherbacks as they live and grow in the *ex situ* environment, and the drivers that influence that survival, as well as the extent to which they survive and thrive after they are returned to their natural ocean habitat.

While acknowledging various assumptions (detailed in the full PVA report, Part II) regarding model structure and input data, the full analysis of *ex situ* management options making up this PVA led to the following observations:

- When in situ management activities were implemented at relatively low levels (bycatch mortality mitigation ≤ 20%), additional increases in nesting female abundance through the application of any form of *ex situ* management of the Mexico subpopulation were only modest across the full duration of the simulation (e.g., 20% bycatch mortality mitigation: addition of up to 14 nesting females at model year 60). With higher levels of bycatch mortality mitigation (≥25%), increases in abundance were more pronounced when implementing *ex situ* management (e.g., 40% bycatch mortality mitigation: addition of up to 123 nesting females at model year 60). As expected, additional implementation of *ex situ* management at greater levels of bycatch mortality mitigation produced larger gains in nesting female abundance across longer timeframes.
- Across the full duration of the simulations, intermediate and high levels of egg translocation management effort (4000 – 6000 eggs) resulted in substantial increases in the probability of persistence (defined as at least one female and one male present) of the Mexico subpopulation, even at very low levels of bycatch mortality mitigation effort. Under the highest level of effort in which eggs are collected from an unidentified external source and transported to an incubation facility near the recipient destination where they are incubated and hatchlings raised in the rearing facility for three months and then released at an appropriate location offshore at three months of age (egg translocation scenario C), the risk of local subpopulation extinction after 60 years was almost eliminated.
- Implementing any of the *ex situ* management options – even at relatively low levels of intensity – significantly increased the likelihood of persistence of the Costa Rica subpopulation after 30 years when additional in situ management activity was not implemented. After 60 years, *ex situ* management options significantly improved the probability of persistence for the Costa Rica subpopulation, particularly at lower levels of additional bycatch mortality mitigation. These relatively large improvements in population persistence were accompanied by very small increases in the predicted number of nesting females, especially at 60 years. In this case, improved persistence of the Costa Rica subpopulation population was achieved by increasing the abundance of juvenile and subadult individuals through *ex situ* management; unfortunately, the abundance of older turtles was restricted because of higher rates of subadult and adult mortality resulting from continued fisheries bycatch.

It is important to acknowledge that the group of species experts and management authorities that participated in the conservation planning workshops surrounding this PVA did not arrive at a functional definition of what constitutes a meaningful contribution to species recovery for a given management alternative – whether focused on *in situ* or *ex situ* activities. This type of definition is complex, involving both purely biological elements – such as, for example, a threshold increase in population abundance or mean annual growth rate – as well as any number of other factors that could include socio-cultural concerns, economic feasibility, or political realities. Discussions among workshop participants brought forth critical information on the general categories that should be considered when making decisions on future management actions to aid in leatherback turtle conservation. Additional work in this area would greatly improve the conservation management decision-making process.

Overall, the analysis described here suggested that egg translocation options hold greater promise then head-starting as an ex situ option for contributing to overall Eastern Pacific leatherback turtle conservation management. This should not be surprising on a simple numerical basis, as the individuals subject to this kind of *ex situ* management are entirely additive to the subpopulation to which they are translocated. If egg translocation can be successfully implemented, this analysis shows the potential of this management technique for improving subpopulation presence, particularly if fisheries bycatch mortality mitigation is low. It is important to recognize that this improvement in subpopulation persistence is the result of *ex situ* management contributing a substantial number of young turtles to the total subpopulation abundance; while implementing this management option may reduce the chance of the subpopulation disappearing entirely, it does not naturally lead to a similarly substantial increase in nesting females over time. This is the inevitable consequence of unsustainably high mortality of subadults and adults in the face of insufficient bycatch mitigation; a larger number of younger turtles simply serves as more biomass to interact with the fishing gear distributed throughout the Eastern Pacific – often with fatal consequences. Nevertheless, a combined management strategy featuring both in situ and ex situ components could work synergistically to save a subpopulation from extinction in the short-term and, through continued efforts directed at reducing in situ threats to individual survival, ultimately improve long-term prospects for recovery.

The complete PVA report is provided in **Part II** of this document.

FACTS, ASSUMPTIONS, KEY KNOWLEDGE GAPS

As the process progressed it became clear that a mix of facts and assumptions were being discussed, relating to both the potential impacts of ongoing *in situ* conservation interventions, and the practicalities and potential impacts of proposed *ex situ* measures. Time during and between meetings was devoted to stakeholders collating facts, assumptions and knowledge gaps related to both *in situ* and *ex situ* management actions (**Appendix II**). These facts, assumptions and knowledge gaps contributed to the development of the research themes listed in the introduction for this report.

DRAFT *EX SITU* MANAGEMENT SCENARIOS: CONSIDERING PRACTICALITIES

Further to the PVA scenario discussions, stakeholders highlighted that they would like to better understand some of the practicalities that might be involved in undertaking one or more of the *ex situ* management strategies under consideration, in particular financial cost. In this way they could begin to develop a shared understanding of the possible financial resource implications of these strategies. To provide an opportunity to make approximate cost comparisons between the *ex situ* options being proposed, some preliminary figures were compiled[5] (**Table 1-4.**). The costs were composed of a combination of start-up and annual running costs over a 25-year period, to match the PVA projections. Further analysis was undertaken to provide an estimate of the cost per turtle release produced through each scenario to gain an understanding of their relative cost-effectiveness. These figures are included in **Table 1-4**.

It was noted that a significant component of the costs for each scenario was composed of the genetic fingerprinting costs to allow for determining post-release survival. It was also noted that it might not be necessary to genetically-fingerprint all individuals, thereby reducing the overall cost of each scenario[6]. Head-starting and translocation option C (involving an additional prolonged captive rearing and husbandry period) are estimated to be significantly more costly and result in fewer animals released overall, based on the assumptions included in the modelling. Furthermore, the modelling suggests that they would not produce significantly more adult females within the wild population than either of the translocations A or B scenarios. A further break-down of how the costs were determined is provided in **Appendix III**.

[5] Williamson *et al.* (in prep) Potential Interventions to Protect Against the Extirpation of the Eastern Pacific Leatherback Turtle Population. White Paper Report for Upwell Turtles.

[6] Lisa Komoroske and Kelly Stewart suggested that only 12-24 hatchlings per nest would need to be fingerprinted. And after three years, most/all nesting females will be fingerprinted. This approach would reduce the annual costs of genetic fingerprinting of $110,000 per annum (**Table 4**) to between US$42,000 and $67,000; a cost-saving of between 40-60%.

***Ex situ* Scenario**	**Start-up costs**	**Annual costs**	**Total Cost (25 Years) (US$ - Millions)**	**Individuals released at 3 months (Cost per release, US$)**	**12-year-old recruits[7] added to the population (Cost per recruit, US$)**
Head-start – 6000 eggs	**US$600,000** (Set up cost of head-starting facility)	Maintenance: US$200,000 Genetics: US$42,000- 67,000 (fingerprinting) Release: US$80,000	**8.6 – 9.3**	**41,670 (208-223)**	**213 (41,000-43,000)**
Translocation A – 6000 eggs	**US$1,000** (Egg collection and transportation materials)	Maintenance: US$4,000 - $15,000 Genetics: US$42,000- 67,000 (fingerprinting)	**1.3 – 1.9**	**142,500 (9-14)**	**203 (6,000-9,500)**
Translocation B – 6000 eggs	**US$210,000 - $420,000** (Artificial incubation facility)	Maintenance: US$26,000 - $60,000 Genetics: US$42,000- 67,000 (fingerprinting)	**2.4 – 3.0**	**102,600 (24-30)**	**210 (12,000-15,000)**
Translocation C – 6000 eggs	**US$600,000** (Set up cost of head-starting facility)	Maintenance: US$210,000 Genetics: US$42,000- 67,000 (fingerprinting) Release: US$80,000	**9.0 – 9.5**	**39,587 (225-241)**	**203 (44,000-47,000)**

Table 1-4. Approximate, preliminary costs of implementing each scenario at a scale of 6000 eggs per scenario (see Appendix IV for breakdown of equipment list used to estimate costs). Note that genetic finger-printing costs of $110,000 per annum were used to develop the original cost scenarios, based on the assumption that all individuals would need to be fingerprinted. However, in later discussion with relevant experts, it was concluded that annual genetic fingerprinting costs could reasonably be reduced by between 40-60% through a more refined sampling approach. Genetic fingerprinting costs presented in the table represent this revised approach, providing a range depending on the proportion of individuals checked. In each case it is assumed that 250 nesting females and either 12 or 24 hatchlings from each of 91 nests per year would be fingerprinted.

[7] These calculations assume the following: *Ex situ* effort = 6000 eggs; *Ex situ* management location = Mexico (just for demonstration purposes); For head-starting, there is a 25% increase in post-release survival to Age-1 compared to turtles hatched in natural nests.

An additional presentation was given to illustrate some of the steps that could be involved in each of the translocation options being considered, to help visualise what they might look like (**Figure 1-2**).

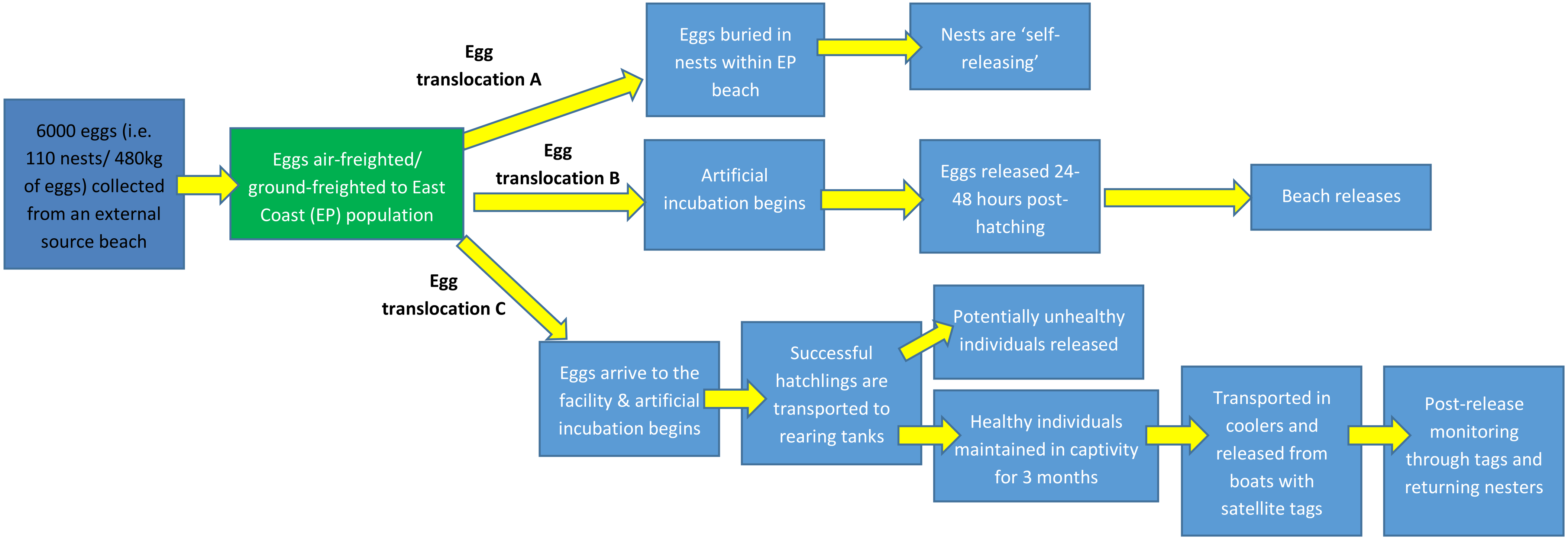

Figure 1-2. Outline of activities to illustrate the three translocation scenarios.

Assumptions

Egg transport survival rate of 95% achieved from external source to EPLB beach
Beach protection measures are in place in EPLB beaches
Within scenarios B and C, where eggs are brought into captivity for a period, best practices are in place to maximise hatching success. This would involve hatching success increasing from 50% to 75% through learning and improvement. Also, the infrastructure would need to exist for this *ex situ* work to proceed.
Genetic fingerprinting takes place prior to release so translocated individuals can be tracked and success measured.
Health monitoring of all individuals reared through scenario C occurs throughout the rearing phase.
For scenario C, survival to 3 months shifts from 25% to 40% as knowledge grows.
Fisheries collaborate to help identify any released turtles caught.

RECOMMENDATION STATEMENT DEVELOPMENT

Following analysis of the PVA models and further discussion around the practicalities of implementing one or more of the *ex situ* management strategies under consideration, stakeholders moved towards developing recommendations. This process involved a combination of the following sequential activities:

1. Completion of a survey to gain an initial assessment of the group's perspective on whether to embark on any *ex situ* management work, be it restricted to research for the present time, or expanded to full-scale *ex situ* management interventions.
2. Plenary discussion to assess levels of agreement around a possible shared recommendation statement.
3. Post-meeting drafting commenting on a possible shared recommendation statement to result in one, consolidated recommendation from the group.

The survey consisted of five questions that related to individual perceptions on the relative value of undertaking some form of *ex situ* management alongside *in situ* work, identification of additional research themes and volunteering to lead on or contribute to the development of one or more of the research themes. The survey was completed by 17 of the workshop participants and the full results (consisting of both English and Spanish responses) are presented in **Appendix V**.

The results of the question concerning individual perspectives on the relative value of undertaking some form of *ex situ* management activities alongside *in situ* work are collated in **Table 1-5.**

Statement options	1 (Strongly disagree)	2	3 (Agree)	4	5 (Strongly agree)	Not sure	TOTAL
Based on what I have heard in the workshop so far, I see no value in undertaking *ex situ* studies to answer some of the related assumptions and knowledge gaps.	47% (8)	29% (5)	12% (2)	6% (1)	6% (1)	0% (0)	100% (17)
I think that before *ex situ* management is undertaken, applied research is required to answer key assumptions and knowledge gaps.	12% (2)	12% (2)	24% (4)	0% (0)	53% (9)	0% (0)	100% (17)
We should start *ex situ* management now and learn through doing.	47% (8)	12% (2)	0% (0)	6% (1)	18% (3)	18% (3)	100% (17)
I do think that someone should begin *ex situ* management trials, though this is not something that I would feel able to contribute to.	25% (4)	19% (3)	25% (4)	6% (1)	19% (3)	6% (1)	100% (16)

Table 1-5. Summary responses to the survey question concerning individual stakeholder perspectives (yellow highlights represent the top two most common responses to each statement).

The survey results were discussed and further analysed during the subsequent meeting of stakeholders, where they were then asked to assign their level of agreement (Kaner et al, 1996) to the following statement (from full endorsement through to veto):

> *'There is uncertainty, therefore we recognise that studies should be undertaken to fill key knowledge gaps and resolve important assumptions in order to reduce levels of uncertainty, and before any decision is taken in whether or not ex situ management (i.e. head-starting and/or translocation within and between populations) could make a significant/important contribution to ongoing conservation efforts for the species, and that would address key knowledge gaps to better understand the biology and conservation of the species.'*

The majority (18; 58%) of participants in the meeting where this statement was developed endorsed the statement, with a further six (19%) agreeing with reservations (**Figure 1-3.**). Nobody vetoed this statement, but it did prompt discussion around what the exact wording of the recommendation resulting from the workshop should be.

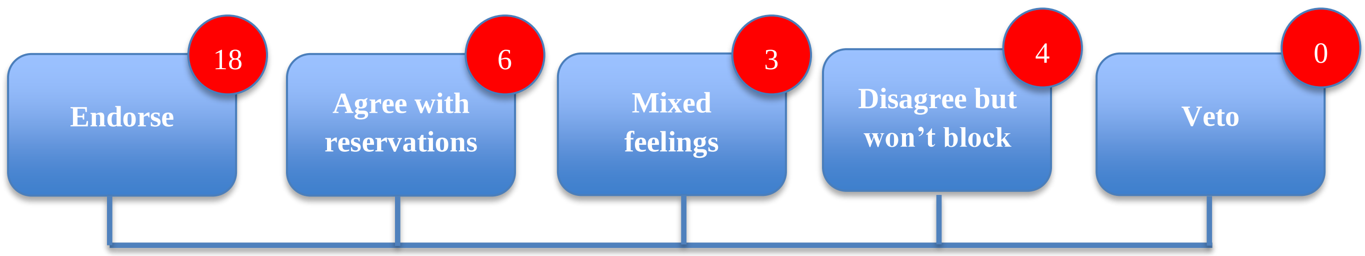

Figure 1-3. 'Voting' results showing levels of agreement from workshop participants with the above statement.

During the meeting, some initial wording was developed with one stakeholder volunteering to take the wording and completing the statement under the following four headings:

- Context for the recommendation
- The recommendation itself
- The justification for this recommendation
- The desired outcomes

The resultant draft statement was then translated to both English and Spanish and circulated (through Google docs) to all workshop participants, for their comments and edits. Two rounds of edits were completed following the last meeting of stakeholders (over a three week period) to result in the recommendation statement presented at the start of this report.

INDIVIDUAL WORKSHOP PARTICIPANT ADDITIONAL COMMENTS

Brian Stacy requested that the following statement be added to the report. "*Although I agree with most of the primary recommendations provided in this report, in my opinion the value of head-starting is questionable beyond the stated knowledge gaps, as has been expressed in prior debates around this practice as related to sea turtles. Robust review and debate of the efficacy of prior head-starting programs was not part of this workshop. In addition, we did not comprehensively discuss or debate the idea of introducing animals from a different, genetically distinct population, which would be required for the proposed ex situ management options. Both topics merit substantial additional consideration".*

POST-WORKSHOP PROCESS SURVEY

The majority (85%) of respondents to the post-workshop evaluation were satisfied or very satisfied with the workshop and the most (85%) felt that the quality of the information available to participants was better or much better than had been expected. Seventy-seven percent of respondents considered that most stakeholders who should have been involved in the workshop were involved, although a lack of government representatives from Mexico and Costa Rica was highlighted.

Enabling all participants to feel equally comfortable contributing their views within the virtual environment was challenging, particularly given the extra barrier in place with the need for translation. Some respondents felt they were unable to contribute as freely as they would have liked. Greater understanding of different stakeholder points of view was generated, in particular of research scientists, wildlife managers and groups linked to *ex situ* conservation work. Participants also generally felt that through the workshop, they had been introduced to new perspectives, now had broader professional networks on which to call on for advice and will continue to exchange information with people met. There was a strong sense from respondents that the workshop had identified important knowledge gaps that needed to be filled to conserve the species. By the end of the workshop survey respondents identified greater agreement on the primary threats to be addressed and the priority conservation strategies and actions necessary to conserve the species. Approximately 70% of respondents were satisfied or very satisfied with the outcomes of the workshop.

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PART II POPULATION VIABILITY ANALYSIS (PVA) REPORT

Population Viability Analysis of the Eastern Pacific Leatherback Turtle

An assessment of *ex situ* management options to inform species conservation

June 2021

Report prepared by

Philip S. Miller, Ph.D.
Senior Program Officer
IUCN SSC Conservation Planning Specialist Group

In consultation with

Upwell
Eastern Pacific Leatherback PVA Workshop participants

Report prepared for

Upwell
99 Pacific Street
Suite 375-E
Monterey, CA 93940

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An assessment of *ex situ* management options to inform species conservation

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Population Viability Analysis of the Eastern Pacific Leatherback Turtle

An assessment of *ex situ* management options to inform species conservation

Executive Summary

The Eastern Pacific population of the leatherback turtle (*Dermochelys coriacea*) has declined dramatically over the past 30 years, due in large part to significant removal of eggs from nesting beaches for human consumption and the bycatch of subadult and adult individuals in fishing gear covering vast areas of both near-shore and pelagic regions within the ocean basin. Local and international conservation organizations are working to reduce this mortality through fisheries bycatch mitigation; despite these efforts, however, the abundance of females nesting on the beaches of Mexico, Costa Rica and nearby areas continues to decline.

In light of this dire situation, some turtle conservation experts are now considering other management activities that may help reverse the current trend toward extirpation of this local leatherback population. A collection of *ex situ* management alternatives – including headstarting turtle eggs in artificial conditions to improve young turtle survival, or translocation of eggs from other regions to support local abundance – have been proposed and are now being actively considered as a potential component of leatherback conservation. These options are examples of a renewed emphasis on exploring all available management techniques, both within and outside the natural habitat of the species, while engaging the full range of relevant stakeholders to improve the prospects for endangered species recovery – a framework known as the One Plan approach.

This document describes a detailed population viability analysis (PVA) of the Eastern Pacific leatherback population, with the explicit goal being to evaluate the potential for *ex situ* management to meaningfully contribute to population recovery. PVA is a valuable process for assembling key demographic and ecological data on the species or population of interest, for projecting the likely fate of that species or population at some time in the future under current management conditions, and for predicting the relative efficacy of alternative management scenarios to increase the future likelihood of population growth and persistence. The computer simulation software *Vortex* (Version 10.4) was used to construct the model. *Vortex* is a stochastic simulation, in which 1000 iterations of each model scenario are conducted to assess the likely future state of a population whose growth or decline is governed by annual environmentally-driven variation in mean breeding and mortality rates.

A PVA model developed by the Laúd OPO Network, published in 2020, was used as the structural basis for the present analysis, with a number of modifications and extensions. Whereas the Laúd OPO Network model focused on predicting future population dynamics of the combined population of turtles nesting in Mexico and Costa Rica, the current *Vortex* model treated each set of national beaches as separate components of the Eastern Pacific metapopulation. This allowed us to estimate future population performance at a finer spatial scale, thereby facilitating a more complete understanding of the prospects for local population recovery under alternative management scenarios. In addition, while the *Vortex* model followed the Laúd OPO Network model by including a set of *in situ* management options (increased hatchling emergence through enhanced nest protection, and reduced subadult and adult mortality through fisheries bycatch mitigation efforts), the present analysis greatly expanded the range of possible *ex situ* management options suitable for analysis compared to the Network's published study.

In situ management was simulated in the model by increasing by 50% the number of hatchlings produced annually from index beaches in Mexico or Costa Rica. In addition, the annual mean rate of subadult and adult mortality was proportionally reduced by 5% to 40%, simulating a range of potentially plausible efforts dedicated to reducing turtle bycatch in both near-shore artisanal fisheries, typically using nets, and pelagic commercial fisheries favoring long-line gear. *Ex situ* management was then added as a conservation activity, and included the following alternatives:

- Headstarting (HS) – In this alternative, leatherback eggs are collected from natural nests in Mexico or Costa Rica, and transferred to a nearby rearing facility. The eggs are hatched and raised in this facility for approximately three months, which was considered to be a reasonable duration for balancing vigorous growth to a suitable size to avoid at least some predation risk, while also minimizing the negative impacts of the artificial environment such as nutritional or behavioral deficits. Individuals are then transported to an appropriate offshore location and released.
- Egg Translocation Option A (ET – A) – Leatherback eggs are collected from an unidentified external source, and deposited in artificial nests in Mexico or Costa Rica in hatcheries at existing nesting beaches where they are allowed to incubate and hatch under natural conditions.
- Egg Translocation Option B (ET-B) – Leatherback eggs are collected from an unidentified external source, transported to a facility near the recipient destination for egg incubation and hatching, and released to an appropriate location near shore 24-48 hours after hatching.
- Egg Translocation Option C (ET-C) – Leatherback eggs are collected from an unidentified external source, and transported to an incubation facility near the recipient destination; eggs are incubated and hatchlings raised in the rearing facility for three months as in the HS management option; individuals are released at an appropriate location offshore at three months of age.

Key assumptions that underlie each *ex situ* management option, specifically those that inform model input parameters defined by high levels of uncertainty, were identified and clearly discussed in the description of each management option. These management options were imposed in the model over a 25-year period, considered to be a logistically feasible time period for this type of intervention. Each option was evaluated at three different levels of intensity, defined by the number of leatherback eggs collected each year of the program: 2000, 4000, or 6000 eggs.

If we assume that management activities in place today do not change in the future, our models predicted that both the Mexico and Costa Rica subpopulations would continue to decline at the current rate of approximately 15% per year. These results are in line with those of the previous Laúd OPO Network analysis, indicating a high level of agreement in the predictions made by the two models. The expected number of nesting females in Costa Rica was likely to drop to less than five individuals within approximately 12 years from the start of the analysis (i.e., the year 2032), while the number in the Mexico subpopulation was likely to decline to similar levels in about 25 years (i.e., the year 2045). Model results indicated a high probability (>90%) of the Costa Rica subpopulation becoming extirpated in less than 45 years, and the Mexico subpopulation – as well as the combined metapopulation – becoming extirpated in less than 55 years. Across those model iterations in which extinction occurred (i.e., abundance declines to zero or only one sex remains), the mean time to extinction was just 31 years for Costa Rica and 42 years for Mexico. These results demonstrate the higher risk of local nesting population extirpation which is not evident in the Laúd OPO Network analysis that evaluates the extinction risk across the combined metapopulation.

Reducing subadult and adult leatherback mortality through mitigating fisheries bycatch interactions arrested the rate of subpopulation decline in both Mexico and Costa Rica, but rather aggressive mitigation appeared to be necessary to facilitate sustained increases in nesting female abundance. Since leatherback females must survive for at least 12 years before becoming reproductively active, the impacts of both improved nest protection and survival of older age classes were not noticeable for at least a decade after the onset of the simulation. Sustained subpopulation growth in the Mexico subpopulation was achieved when the extent of bycatch mortality mitigation reached 30% (i.e., when the annual subadult and adult mortality rate is proportionally reduced by 30%). Note, however, that this threshold target of bycatch mortality mitigation was successful only at bringing the mean nesting female abundance among Mexico beaches back up to its initial value of 54 individuals after 60 years of the simulation. Higher levels of bycatch mitigation (i.e., 40% reduction) led to comparatively substantial subpopulation growth, with nearly 180 nesting females in this subpopulation at year 60. In stark contrast to the predictions for Mexico, the Costa Rica subpopulation failed to return to the initial abundance of nesting females even with the most aggressive level of bycatch mortality mitigation tested here. The scenario featuring 40% bycatch mortality mitigation resulted in a final mean nesting female abundance of 10.9 individuals, just 68% of the original value of 16 nesting females.

Before engaging in a full analysis of the potential benefit of *ex situ* management, a separate analysis was conducted on the sensitivity of model predictions to uncertainty in a key input parameter: survival to one year old of young turtles released at three months of age from headstarting facilities. The technical difficulty of monitoring these young individuals over a large area of ocean habitat means that very limited data are available to inform this important parameter. Proponents of *ex situ* leatherback turtle management propose that careful rearing of young turtles in controlled environments can lead to higher growth rates that would produce larger individuals that could more easily escape predation after release and therefore, enjoy higher first-year survival – perhaps up to 50% higher through the nine months after release to one year of age. On the other hand, rearing turtles in these conditions could lead to injuries, disease complications and behavioral deficits that could reduce post-release survival to a lower level (worst case scenario: -25%) than that among wild turtles that hatch from natural nests.

Our sensitivity analysis indicated that if survival of headstarted individuals is only marginally improved compared to wild-born turtles, a dedicated headstarting effort was unlikely to provide meaningful benefit if conducted parallel to additional *in situ* management activities. Moreover, if released individuals are not as robust as their wild counterparts, and consequently suffer higher rates of mortality in their new wild environment, a headstarting program would actually be detrimental to the subpopulation to which that management activity is applied. In light of this analysis and associated discussions that were conducted as part of this larger project, it is recommended that any proposal to initiate a headstarting program would be preceded by extensive research and experimental trials to better understand the relative survival of hatchling leatherbacks as they live and grow in the *ex situ* environment, and the drivers that influence that survival, as well as the extent to which they survive and thrive after they are returned to their natural ocean habitat.

While acknowledging the various assumptions regarding model structure and input data, the full analysis of *ex situ* management options making up this PVA led to the following observations:

- When *in situ* management activities were implemented at relatively low levels (bycatch mortality mitigation ≤ 20%), additional increases in nesting female abundance through the application of any form of *ex situ* management of the Mexico subpopulation were only modest across the full duration of the simulation (e.g., 20% bycatch mortality mitigation: addition of up to 14 nesting females at model year 60). With higher levels of bycatch mortality mitigation (≥25%), increases in abundance were more pronounced when implementing *ex situ* management (e.g., 40% bycatch mortality mitigation: addition of up to 123 nesting females at model year 60). As expected, additional implementation of *ex situ* management at greater levels of bycatch mortality mitigation produced larger gains in nesting female abundance across longer timeframes.
- A headstart (HS) option using eggs collected from local beaches appeared to provide the least benefit to each of the subpopulations, in terms of nesting female abundance across the range of

tested intensities. This result is consistent with general life-table analysis of species with a life history that is characterized by a relatively delayed age of maturation, high fecundity, and low offspring survival. In this type of case, population growth is more strongly influenced by survival of older age classes.

- For the Mexico subpopulation, egg translocation type-A and type-B scenarios provided roughly equal benefit – and at a markedly higher level – than HS scenarios. The egg translocation type-C scenarios, featuring both egg translocation and additional rearing of hatchlings in *ex situ* facilities before release (similar to the HS option), provided the greatest relative benefit to intermediate and longer-term abundance of nesting females.
- Across the full duration of the simulations, intermediate and high levels of egg translocation management effort (4000 – 6000 eggs) resulted in substantial increases in the probability of persistence (defined as at least one female and one male present) of the Mexico subpopulation, even at very low levels of bycatch mortality mitigation effort. Under the highest level of effort for the ET-C management option, the risk of local subpopulation extinction after 60 years was almost eliminated.
- Applying the same level of *ex situ* management intensity to the smaller Costa Rica subpopulation led to comparatively larger proportional increases in nesting female abundance over time relative to the results observed for the Mexico subpopulation. Despite these positive gains, the Costa Rica subpopulation remained much smaller than the Mexico subpopulation after combined management, a consequence of the very small current abundance and slow rates of predicted population growth. Once again, headstarting (HS) options appeared to provide relatively little numerical benefit to abundance, while egg translocation options led to larger gains.
- Implementing any of the *ex situ* management options – even at relatively low levels of intensity – significantly increased the likelihood of persistence of the Costa Rica subpopulation after 30 years when additional *in situ* management activity was not implemented. After 60 years, *ex situ* management options significantly improved the probability of persistence for the Costa Rica subpopulation, particularly at lower levels of additional bycatch mortality mitigation. As acknowledged previously, these relatively large improvements in population persistence were accompanied by very small increases in the predicted number of nesting females, especially at 60 years. In this case, improved persistence of the Costa Rica subpopulation population was achieved by increasing the abundance of juvenile and subadult individuals through *ex situ* management; unfortunately, the abundance of older turtles was restricted because of higher rates of subadult and adult mortality resulting from continued fisheries bycatch.

It is important to acknowledge that the group of species experts and management authorities that participated in the conservation planning workshops surrounding this PVA did not arrive at a functional definition of what constitutes a meaningful contribution to species recovery for a given management alternative – whether focused on *in situ* or *ex situ* activities. This type of definition is complex, involving both purely biological elements – such as, for example, a threshold increase in population abundance or mean annual growth rate – as well as any number of other factors that could include socio-cultural concerns, economic feasibility, or political realities. Discussions among workshop participants brought forth critical information on the general categories that should be considered when making decisions on future management actions to aid in leatherback turtle conservation. Additional work in this area would greatly improve the conservation management decision-making process.

Overall, the analysis described here suggested that egg translocation options hold greater promise then headstarting as an *ex situ* option for contributing to overall Eastern Pacific leatherback turtle conservation management. This should not be surprising on a simple numerical basis, as the individuals subject to this kind of *ex situ* management are entirely additive to the subpopulation to which they are translocated. This is different from a headstarting program, in which the survival of a sample of turtle eggs from the local beach is targeted to improve survival above what would otherwise be expected if the eggs were allowed to hatch naturally and the hatchlings were to attempt to survive the earliest weeks of life after leaving the nest.

Despite the apparent benefits that translocation may offer as an *ex situ* management option, there are significant concerns around the capacity of translocated individuals to successfully adapt to their new surroundings. For example, translocation carries the risk of introducing novel pathogens to naïve populations, and could also lead to disruption of local population genetic structure through admixture of genes from different populations. In addition, turtles may be genetically “hard-wired” to use various navigational cues to successfully thrive in the ocean basin from which they and their ancestors are derived. Translocating individuals from one basin to another, or perhaps even among different locations within the same basin, may disrupt their ability to display normal ecological behaviors necessary for feeding, breeding, and nesting. However, there is simply no agreement yet on whether this is a significant problem that would restrict the opportunities for successful translocation of leatherback eggs to the Eastern Pacific. Once again, dedicated study of this issue through appropriate experimentation should be required before translocation is adopted as an *ex situ* management option of choice for leatherback conservation.

Many of the *ex situ* management strategies evaluated here could be important tools for reducing the likelihood of local extinction of both the Mexico and the Costa Rica subpopulations – in essence, using *ex situ* management to “buy time” for saving the subpopulations from later extinction. This concept is explicitly recognized by international conservation organizations such as the IUCN as an important role that *ex situ* management can play in species conservation. If egg translocation can be successfully implemented for the reasons provided previously, this analysis shows the potential of this management technique for improving subpopulation presence, particularly if fisheries bycatch mortality mitigation is low. It is important to recognize that this improvement in subpopulation persistence is the result of *ex situ* management contributing a substantial number of young turtles to the total subpopulation abundance; while implementing this management option may reduce the chance of the subpopulation disappearing entirely, it does not naturally lead to a similarly substantial increase in nesting females over time. This is the inevitable consequence of unsustainably high mortality of subadults and adults in the face of insufficient bycatch mitigation; a larger number of younger turtles simply serves as more biomass to interact with the fishing gear distributed throughout the Eastern Pacific – often with fatal consequences. Nevertheless, a combined management strategy featuring both *in situ* and *ex situ* components could work synergistically to save a subpopulation from extinction in the short-term and, through continued efforts directed at reducing *in situ* threats to individual survival, ultimately improve long-term prospects for recovery.

Finally, it is important to recognize that the decision regarding if *ex situ* management is to be employed, and if so, how it could best contribute to leatherback conservation in the Eastern Pacific, is not to be based solely on the results of this quantitative analysis. As with any high-stakes decision in species conservation, numerous factors should be considered together before a particular action or set of actions is taken. For example, careful consideration must be given to the estimated financial cost of the *ex situ* management options considered here, so that a responsible measure of cost-effectiveness – the extent of subpopulation abundance benefit per unit financial expenditure – can be calculated. In an identical manner, the financial costs associated with a given level of *in situ* fisheries bycatch mitigation should also be estimated so that a meaningful comparison across the full suite of population management options can be undertaken. Other important factors identified by participants included: minimize demographic impacts to source populations, avoid compromising efforts to secure funding for *in situ* management activities, and improve opportunities for local community engagement in recovery efforts. Using this broad approach, those engaged in leatherback conservation in the Eastern Pacific can create a unified vision for what is required to save these subpopulations from extinction.

Introduction

The Eastern Pacific population of the leatherback turtle (*Dermochelys coriacea*) has declined dramatically over the past 30 years, due largely to significant removal of eggs from nesting beaches for human consumption and the bycatch of subadult and adult individuals in fishing gear covering vast areas of both near-shore and pelagic regions within the ocean basin (e.g., Sarti Martinez et al. 2007; Spotila et al. 2000; Shillinger et al. 2008; Wallace et al. 2013a; Roe et al. 2014; Hoover et al. 2019; Degenford et al. 2021). Continued persistence of this population will be critically dependent on swift and aggressive conservation action.

Efforts to address the grave threat posed by increased mortality arising from fisheries bycatch are ongoing (e.g., Laúd OPO Network 2013). Despite these dedicated activities, it is evident that other conservation activities may be necessary to reverse the seemingly inevitable trend toward extirpation of this local leatherback population. The adoption of *ex situ* management techniques – including headstarting turtle eggs in artificial conditions to improve young turtle survival, or translocation of eggs from other regions to support local abundance – has been proposed and is now being actively considered as a potential component of leatherback conservation. The consideration of *ex situ* conservation options has recently received significantly increased attention in the global conservation community as the risk of extinction of many species worldwide continues to increase (e.g., IUCN/SSC 2014; Taylor et al. 2020).

In the spirit of the IUCN's One Plan approach (Byers et al. 2013), this document describes a demographic analysis and quantitative risk assessment for the Eastern Pacific population segment of the leatherback turtle. Specifically, we define the Eastern Pacific population to include primary (index) nesting beaches in Mexico and Costa Rica, in keeping with recent published analyses (e.g., Laúd OPO Network 2020). The goals of the analysis are to project the likely fate of this population if current conditions are to persist, and to then examine the potential for specific management alternatives – targeting different aspects of the species' life history – to contribute to long-term population recovery. More specifically, the analysis is designed to address the following questions:

- Can *ex situ* management activities – such as headstarting of eggs collected from local beaches, or translocation of eggs from other regions of the species distribution – contribute significantly to recovery of the Eastern Pacific leatherback (hereafter, EPLB), in combination with other *in situ* management activities such as mitigation of fisheries bycatch mortality?
- What level of effort would be required for one or another *ex situ* management activity to make significant contributions to Eastern Pacific leatherback population viability?
- Should consideration be given to prioritizing nesting beaches in Mexico or Costa Rica for *ex situ* management if it were to be implemented?

In addition, the analysis is meant to stimulate discussion around the following key organizational questions that guide the management decision-making process:

- What are the key elements of a successful and meaningful *ex situ* management effort? Such elements may include:
    - Hatching rate;
    - Survival to release;
    - Post-release survival.
- What are the critical areas of uncertainty in our collective knowledge of EPLB biology that influence our ability to predict population responses to simulated management actions?
- What would it mean for *ex situ* management activities to "contribute significantly" to improving EPLB population status?
- What are the demographic metrics that would be used to evaluate the success of a given management activity? Such metrics might include:

- o Annual nesting female abundance;
- o Mean annual population growth rate;
- o Mean reproductive output of a population.

Population viability analysis (PVA) can be a very useful tool for addressing these types of questions in the context of species conservation planning. These tools and techniques are very well-suited for investigating current and future demographic dynamics of leatherback populations in the Eastern Pacific, and can assess the relative consequences of alternative management strategies to suggest which practices may be the most effective in managing populations that are threatened with extinction.

Vortex, a simulation software package written for PVA (Lacy and Pollak 2020; Lacy et al. 2017), was used to conduct this analysis. The *Vortex* package is a simulation of the effects of a number of different natural and human-mediated forces – some, by definition, acting unpredictably from year to year – on the health and integrity of wildlife populations. *Vortex* models population dynamics as discrete sequential events (e.g., births, deaths, sex ratios among offspring, catastrophes, etc.) that occur according to defined probabilities. The probabilities of events are modeled as constants or random variables that follow specified distributions. The package simulates a population by recreating the essential series of events that describe the typical life cycles of sexually reproducing organisms. See Figure 2-1 for a generalized diagram of a typical annual life-cycle (or timestep) as simulated in *Vortex*.

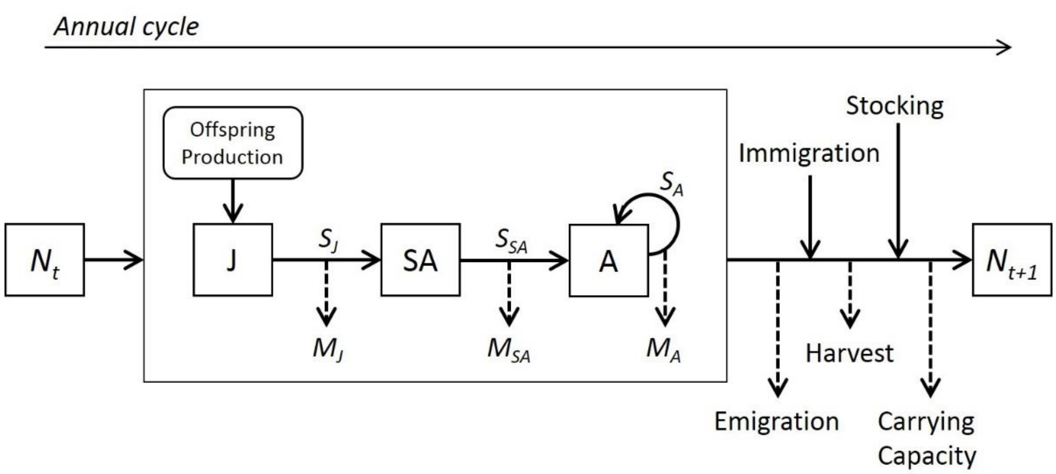


Figure 2-1. General schematic diagram depicting the series of events making up a typical annual cycle (timestep) in the PVA modeling software package *Vortex,* representing simulated change in population abundance from N_t to N_{t+1}. Enclosed portion of the diagram shows the production of juveniles (J) and the transition of individuals among the juvenile, subadult (SA) and adult (A) stages, determined by annual age-specific survival (S_x) rates and their complimentary mortality (M_x) rates. On the right side of the diagram, processes above the timeline act to increase population abundance, while those below the timeline decrease abundance. The aggregate effect of these various demographic processes results in a new population abundance at the end of the timestep. For more information on *Vortex*, see Lacy et al. (2017).

PVA methodologies such as the *Vortex* system are not intended to give absolute and accurate "answers" for what the future will bring for a given wildlife species or population. This limitation arises simply from two fundamental facts about the natural world: it is inherently unpredictable in its detailed behavior; and we will never fully understand its precise mechanics. Consequently, many researchers have cautioned against the exclusive use of absolute results from a PVA in order to promote specific management actions for threatened populations (e.g., Ludwig 1999; Beissinger and McCullough 2002; Reed et al. 2002; Ellner et al. 2002; Lotts et al. 2004; Lacy 2019). Instead, the true value of an analysis of this type lies in the assembly and critical analysis of the available information on the species and its ecology, and in the ability to compare the quantitative metrics of population performance that emerge from a suite of simulations, with each simulation representing a specific scenario and its inherent assumptions about the available data and a proposed method of population and/or landscape management. Interpretation of this type of output depends strongly upon our knowledge of leatherback turtle biology, the environmental conditions affecting the species, and possible future changes in these conditions. Under thoughtful and appropriate interpretation, results from PVA efforts can be an invaluable aid when deriving meaningful and justifiable endangered species recovery criteria (Himes Boor 2014; Doak et al. 2015). Overall, population models used in PVA provide a framework not only for analyzing complex situations impacting endangered species persistence, but also for documenting assumptions and methods underlying the analyses, reviewing and improving population assessments, and integrating new threat information into our collective understanding of species dynamics.

Guidance for PVA Model Development

The demographic analysis described in this report was developed by the author, with close consultation and collaboration with staff scientists from Upwell and their collaborators, and with the collective advice and expertise of a group of participants in a series of virtual workshop sessions held in November and December 2020. The analysis described in Laúd OPO Network (2020) was used as the foundation for our population viability model. The Network analysis is based on a stochastic age-structured matrix model of the regional leatherback population making up the large majority of the Eastern Pacific nesting population. This regional population was taken to be made up of the index nesting beaches in Mexico and Costa Rica; while the demographic characteristics of each national set of beaches (i.e., subpopulation) were described separately, the Network analysis reported predicted future nesting female abundance only for the aggregate regional population.

Since the two national populations differ in nesting female abundance, and are each characterized by different rates of population growth (decline) in the recent past, it seems prudent to consider them as separate subpopulation components of the greater Eastern Pacific leatherback population. In addition, the need for developing population management recommendations at the national level supports this approach. Consequently, the PVA model presented in this report features an explicit metapopulation structure, with the nesting beaches of Mexico and Costa Rica treated as separate entities with some demographic connectivity that is explained in the next section of this report.

The starting point for our analysis is the historic data on nesting female abundance for the collection of index beaches in Mexico and Costa Rica (Figure 2-2). These abundance data can be used to estimate mean annual population growth rates (λ) for each national set of beaches, which can then serve as the foundation on which demographic rates – namely, annual survival rates of subadults and adults – can be calibrated to create a reasonably realistic portrayal of population growth over the recent past. This can serve as a meaningful initialization of each subpopulation for prospective analysis of the relative efficacy of different management alternatives involving both *in situ* and *ex situ* activities.

Raw data on nesting female abundance were not available at the time of this analysis. Therefore, the abundance estimates added to Figure 2-2 are derived from extraction of point data using the software DataThief III (Tummers 2006: https://datathief.org/). Calibration of abundance estimates derived using this method with known abundance data (Spotila et al. 2000) revealed an average error rate of just 0.8%.

1988 was chosen for the beginning of this analysis as it is also the starting point for retrospective abundance data used in model projections presented in the Network PVA paper.

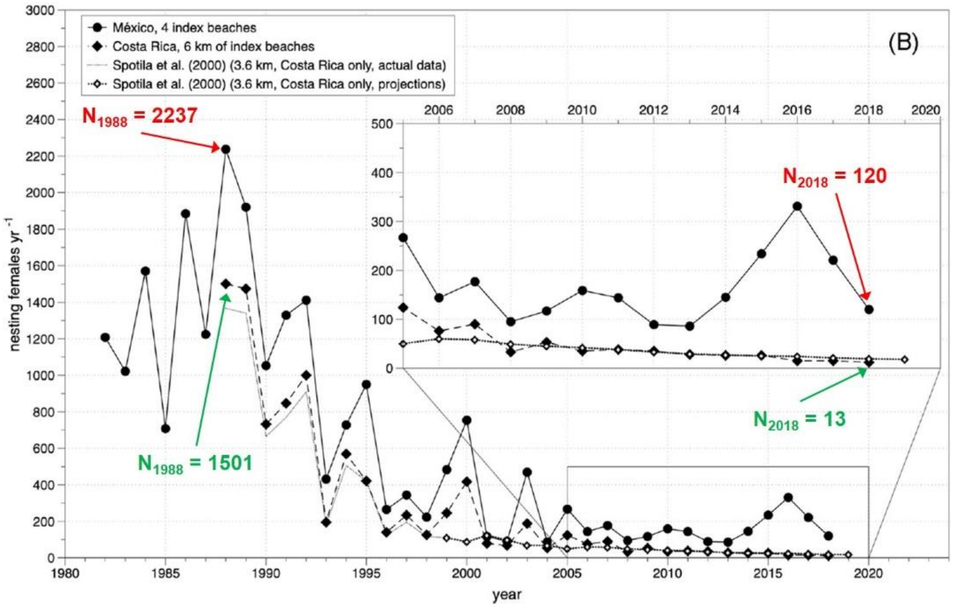


Figure 2-2. Historic data on abundance of nesting female leatherback turtles observed on index beaches of Mexico and Costa Rica. Figure adapted from Laúd OPO Network (2020), Figure 1B. Abundance estimates for each country in 1988 and 2018 are marked on the plot (Mexico: red; Costa Rica: green), identifying the starting and ending dates for the retrospective analysis described in this report.

The primary sources for these data are not specified in the original demographic analysis of Laúd OPO Network (2020). Moreover, there may be potential issues with interpreting data for the Mexico nesting beaches. As presented in Laúd OPO Network (2020), the Mexico data include “4 index beaches”. However, the caption for their Figure 1B (not reproduced here) indicates that the list of index beaches includes Tierra Colorado, Barra de la Cruz, and Cahuitán throughout the full time period 1988 – 2018 (the focal period identified by paper authors), Mexiquillo until 2013, and Chacahua during the period 2011 – 2018. This variability in the dataset resulted from changes in the availability of resources for beach monitoring, addition of beaches after expansion of the national monitoring program, and security issues that disrupted or prohibited monitoring (B. Wallace, pers. comm.). Despite these complexities, these abundance data represent the best information available to examine regional population dynamics of nesting leatherbacks.

The primary goal of this project is to expand upon the analysis of Laúd OPO Network (2020), building on their evaluation of various management options that focused heavily on both improved hatchling production through nesting beach protection and increased survival of subadult and adult turtles through mitigation of fisheries bycatch mortality. Specifically, the historic data are used to generate reasonable estimates of mean annual reproduction and survival rates that describe each national subpopulation as of the beginning of the prospective simulation – taken here to approximate the year 2020. Projections of future nesting female abundance are then generated using the PVA model under a set of different assumptions, namely: (1) no change to current management practices, in other words, maintaining the status quo; (2) implementing different intensity levels of *in situ* management; and (3) combining *in situ* management with different types of *ex situ* management, applied across a range of intensity levels. In this way, we can assess the additional benefit that *ex situ* conservation could potentially bring to overall leatherback turtle conservation across the Eastern Pacific.

Input Data for PVA Simulations

General Characteristics of Model Structure

Age structure: In keeping with the model structure used in Laúd OPO Network (2020), we defined the following development stages that make up the leatherback turtle life cycle:

- Egg (Age-0)
- Hatchling –emerging from the nest and successfully reaching the water's edge
- Yearling – surviving from water's edge to 12 months of age (Age-1)
- Juvenile – Age-1 to Age-3
- Subadult – Age-3 to Age-12
- Adult – Age-12+

Sex structure: While the Laúd OPO Network (PVA) demographic analysis employed a traditional female-only matrix model of leatherback turtle population dynamics, the present model simulates the dynamics of both females and males. Given the significant female bias in hatchling production currently observed on these nesting beaches (see below), it is therefore possible for local (subpopulation-specific) extinction to occur through the elimination of males.

Metapopulation structure: As described above, the present analysis treats the Mexico and Costa Rica adult female nesting populations as demographically distinct entities. This means that, while adult females may move to common pelagic zones for feeding and other activities between nesting events, they exhibit 100% fidelity to the country in which they were born when choosing a site for nesting. In contrast, males remain relatively more dispersed in the open ocean throughout the year, although they may congregate in more distinct areas for breeding with females (Reina et al. 2005). It is likely over time, however, that males will breed with females that nest on beaches either in Mexico or in Costa Rica; in other words, males may "disperse" between nesting female subpopulations from one year to the next.

In the language of our *Vortex* population dynamics model, we set up our models as a metapopulation composed of two subpopulations (Mexico, Costa Rica). We assume that females do not "disperse" between the two subpopulations. In contrast, adult males are assumed to "disperse" between the two subpopulations rather freely. This is simulated through a 50% annual probability that an adult male that is currently assigned to one subpopulation will "disperse" to the other subpopulation in the following year, and therefore be able to breed with an adult female belonging to that subpopulation.

Model version: *Vortex* version 10.4.0.0 (March 2020).

Simulation mode: Variable. At relatively low levels of fisheries bycatch mortality mitigation (0 – 15%, see subsequent information for definition of mitigation scenarios), *Vortex* was implemented as an individual-based simulation. This mode allows for the impacts of subtle stochastic demographics to influence the growth dynamics of small populations in more realistic ways. Under higher levels of bycatch mitigation (20% and above), computational demands necessitated a switch in *Vortex* to a population-based mode that behaves in a manner very similar to a traditional matrix analysis like that used in Laúd OPO Network (2020). Elimination of some subtle stochastic demographics in this analysis mode may lead to a very slight under-estimation of subpopulation extinction risk in any one management scenario, but the effect is considered to be quite small.

Timestep definition: Our implementation of *Vortex* for this PVA is based on a pre-breeding census, with nesting female abundance therefore tallied just before females haul themselves on shore to nest. Reproduction and mortality are described on an annual basis, with the next census taken at the onset of the next breeding season. Therefore, the model timestep is defined for this analysis as one year.
Number and duration of iterations: 1000 replicates for each unique input dataset (scenario), projected forward for 60 years from simulation year 0 (taken to be the year 2020). The choice of model duration was consistent with the trajectories reported in the analysis of Laúd OPO Network (2020).

Primary output metrics: Annual nesting (adult) female abundance, and probability of population persistence. Reporting nesting female abundance, of course, corresponds to the main focus of population-level monitoring efforts, and is a highly informative measure of long-term impacts of demographic threats across multiple developmental stages.

General Model Input Parameters

Reproductive parameters

Breeding system: Polygynous, as adult males are assumed to be capable of breeding with multiple females in any one breeding season.

Age of first breeding: In keeping with the analysis of Laúd OPO Network (2020), we assume that adult females are first capable of reproduction at 12 years of age. Expert judgment among those PVA workshop participants with knowledge of the species assumed that male leatherbacks were likely to begin breeding at a slightly later stage. Therefore, onset of breeding for males was set at 16 years of age.

Maximum age of reproduction (lifespan): Leatherbacks are assumed to be capable of breeding throughout their adult life, i.e., no reproductive senescence is included in these models. We assume here that leatherbacks can live up to 40 years of age. The typical lifespan of leatherback turtles is highly uncertain, with recent studies suggesting shorter (34-38 years: Avens et al. 2020), or longer (90 years: Mayne et al. 2020) lifespan estimates based on different analytical methods. Given typical mortality rates used in this analysis (see below), the likelihood of an individual leatherback reaching this maximum age is very low. Our models, therefore, are rather insensitive to this parameter.

Percentage of adult females nesting per year: The matrix model of Laúd OPO Network (2020) included a specific function for the probability of nesting for a given female based on the number of years since she last nested, otherwise known as the remigration or renesting interval. The computational structure of our *Vortex* model does not easily account for that type of detailed data. Instead, we aggregated that renesting interval information into a simplified annual probability of an adult female nesting in any given year. The renesting data of Laúd OPO Network (2020) approximate a 30% annual probability of nesting for a typical adult female. This specification allows for individual females to exhibit variable renesting intervals as a result of the probabilistic sampling of individuals for breeding in a particular simulation year. Random environmental variability in the mean annual probability of nesting was expressed as a 5% standard deviation around the binomial mean probability. In addition, we assume that breeding in the adult cohort of each population does not exhibit density dependence.

Number of clutches per year: Laúd OPO Network (2020) reported that nesting leatherback females produce an average of six clutches per nesting season. For overall model simplicity, we have aggregated these multiple clutches into a single “brood” for each year that an adult female comes ashore to nest. Test models that explicitly model multiple nests per year, producing the same total number of eggs relative to the more simple treatment of reproduction as a single clutch of eggs, show identical population dynamics to the chosen approach of modeling a single aggregate brood (detailed results available upon request).

Number of offspring per adult female: All models in this analysis feature reproduction defined as the production of eggs by a given nesting female. Laúd OPO Network (2020) report an average of 390 eggs produced per nesting female in Mexico (5.9 nests, 66.0 eggs per nest), and 403 eggs per nesting female in Costa Rica (6.1 nests, 66.0 eggs per nest). Environmental variability in annual egg production among adult females nesting in a given year was expressed as a standard deviation of 80 eggs around the specified means for each country.

Sex ratio of hatchlings: Per specific studies (Santidrián Tomillo et al. 2015; Binckley et al. 1998) that are summarized in Laúd OPO Network (2020), we likewise assume that 84% of hatchlings are female.

<u>Mortality parameters</u>

Yearling mortality: For the Mexico population, Laúd OPO Network (2020) report that of the 390 eggs produced per nesting female, a total of 181 hatchlings successfully reach the water's edge. This translates into an initial survival rate of 0.464 (note that this is slightly different than the value they report (0.47) in their Table 1). In addition, they report first-year survival (water's edge to one year of age) as 0.063, which is based on a simple logical calculation presented by Spotila (1996). Taken together, these values produce a total first-year survival rate from egg to one year of age of (0.464)*(0.063) = 0.0292. This translates into a total first-year mortality rate of 97.08% for the Mexico subpopulation.

Using a similar methodology for the Costa Rica subpopulation, we know from Laúd OPO Network (2020) that 123 hatchlings successfully reach the water's edge (i.e., a survival rate of 0.305). Applying the same survival rate of 0.063 from water's edge to one year of age, we derive a total survival first-year survival rate of (0.305)*(0.063) = 0.0195. This translates into a total first-year mortality rate for the Costa Rica subpopulation of 98.05%. Note that this slightly lower first-year survival for hatchlings in Costa Rica may reflect additional continued pressure on overall hatchling production on these beaches compared to those in Mexico (Santidrián Tomillo 2010).

Both populations featured a standard deviation around the specific means of 3.0% representing the impacts of environmental variability on mean annual mortality.

Juvenile mortality: Survival of Age-1 to Age-3 individuals was taken to be 0.50, in keeping with the analysis of Laúd OPO Network (2020). In the absence of direct observation of monitored turtles, this value was itself derived assuming a conservative estimate of survival in a population that was not subjected to anthropogenic mortality of subadults and adults, therefore leading to a stable population that was neither growing nor declining. This derived estimate translates into a mean annual mortality rate of 50%. Environmental variability for this estimate was set at 5.0%.

Subadult and adult mortality: Laúd OPO Network (2020) report subadult and adult mortality equal to 29.5% and 21.2% for Mexico and Costa Rica, respectively. Following data reported in earlier studies (Jones et al. 2011; Stewart et al. 2007), mortality was assumed in the Network analysis to be equal across subadults and adults. Direct application of these data in the present population model, however, led to inaccurate retrospective trajectories of historic nesting female abundances in both countries (see section on Retrospective Analysis). In light of these unsatisfactory results, subadult and adult mortality rates were adjusted to new values that led to more accurate retrospective abundance trajectories. These new values for mean annual mortality were set at 24.5 ± 5.0% and 25.2 ± 5.0% for Mexico and Costa Rica, respectively.

Catastrophes

The PVA model described here does not include a specific catastrophic event, i.e., one with a low frequency of occurrence but with the potential for a major population-level impact. This was largely based on a desire to keep our model more closely aligned with the previous analysis (Laúd OPO Network 2020). Future applications of this model could be expanded to include impacts of climate change, such as a periodic weather event based on the El Niño Southern Oscillation (ENSO). This type of event may lead to significant changes in environmental conditions that are translated into reduced reproductive success and/or age-specific survival (e.g., Reina et al. 2009; Saba et al. 2008, 2012; Willis-Norton et al. 2015; Santidrián Tomillo et al. 2020).

Inbreeding depression

As in the case of catastrophes, we similarly chose to exclude inbreeding depression as a factor influencing age-specific survival from our analysis. Specific data on the strength and mode of action of inbreeding depression are not available for leatherback turtles, making its detailed inclusion in the present analysis difficult at best.

Initial population size

The initial abundance of individuals across all age classes was obtained from analyzing results from the termination of our retrospective analysis that roughly corresponds to the current time period. The Mexico subpopulation was initialized with 179 adult females (corresponding to approximately 54 nesting females), while the smaller Costa Rica subpopulation was initialized with 54 adult females (corresponding to approximately 16 nesting females). Adult females were distributed among the specific age classes roughly in accordance with a stable age distribution. Initial abundance values for adult males were set at 14 and 7 for Mexico and Costa Rica, respectively. These values are roughly in accord with the significant female bias among hatchlings, as well as the additional mortality incurred by males as they continue to grow to an older age before they become adults. All other younger age-sex classes were distributed in a manner consistent with this distribution of adults, and assuming a roughly stable age distribution (in the absence of other information).

These initial abundances used here do not represent the total number of leatherback turtles making up the full Eastern Pacific population, as females are known to nest at other beaches in Mexico and Costa Rica, as well as other nearby countries such as Nicaragua, Panama and Ecuador. The current model is developed to align with the analysis of Laúd OPO Network (2020) which focused on the index beaches of Mexico and Costa Rica. Furthermore, the comparisons presented in this analysis are expected to be qualitatively identical should other subpopulations be added to the analysis in the appropriate manner.

Carrying capacity

In the typical *Vortex* modeling framework, a population is allowed to increase in abundance under favorable demographic conditions (and without explicit specification of density dependence) until the carrying capacity K is reached. When this occurs, individuals are randomly removed (simulating additional mortality under these limiting conditions) according to the age and sex structure of the population in order to bring the population back down to the value of K. In this manner, we therefore simulate a ceiling-type density dependence. In the absence of more detailed information on region-wide ecological characteristics that could be used to derive an estimate for this parameter, we simply identified the maximum abundance of nesting females observed over the past four decades summarized in Figure 2-1. This maximum value for both the Mexico and Costa Rica subpopulation corresponded to the year 1988, with approximately 2,200 and 1,500 females, respectively. Given our estimated proportion of adult females that are expected to nest in an average year, these observations translate into total adult female abundances of approximately 7,300 and 5,000, respectively. We conservatively assume that the total abundance that could be supported in the local marine environment could be slightly larger than the observed maxima – namely, 8,000 and 6,000 adult females for Mexico and Costa Rica, respectively. These are very rough estimates and, in fact, are far beyond the abundances that can be achieved given the demographic characteristics of the subpopulations simulated here.

Simulating *In Situ* Leatherback Turtle Management

For the purposes of our analysis, all PVA scenarios featuring *in situ* leatherback management included the following two components, as explored in Laúd OPO Network (2020):

- Increased emergence – This simulates active beach protection and other activities that improve hatchling production by an estimated 50% over status quo levels. We incorporate this feature by increasing the total survival of individuals that reach the water's edge by 50%, which is a component of the total survival of Age-0 individuals to one year of age.
- Fisheries bycatch mortality mitigation – This is simulated by a proportional decrease in mean annual mortality of subadults and adults, assumed to result from direct mitigation of fatal interactions of turtles with fishing gear (both nets and longlines). For example, if the status quo mean annual mortality rate is 25%, and a management scenario features a 20% reduction in turtle mortality through bycatch mitigation, the resulting modified mortality rate becomes (0.8)*(0.25) = 0.2, or 20%. This calculation assumes that effectively all mortality of subadult and adult leatherbacks is due to fisheries bycatch, as acknowledged by others (e.g., Wallace et al. 2013b). Note that this quantitative approach to simulating bycatch mitigation is different from that of Laúd OPO Network (2020), in which bycatch mitigation was simulated through the proportional increase in survival, and not a decrease in mortality. Because of the complementary nature of numerical expressions of survival and mortality, a specific reduction in survival does not result in equivalent dynamics to the same level of reduction in mortality. Our approach is based on the premise that a management action designed to reduce the number of individuals killed by fisheries interaction is most accurately portrayed through a corresponding reduction in mortality.

  Bycatch mitigation was implemented across a range of intensity levels – from 0% additional mitigation (representing the status quo) to 40% proportional reduction, in increments of 5% reduction. This yields a total of nine categories of *in situ* management for this analysis. For each mitigation level, mortality reduction was assumed to begin in model year 6, simulating the passage of time to agree upon and develop specific mitigation activities. Moreover, the total extent of mortality reduction was assumed to take five years to implement, with the final maximum mortality reduction being realized in model year 15. This level of reduced mortality would remain in effect throughout the duration of the simulation (approximately 45 years). This mechanism of bycatch mortality mitigation is very close to that implemented in Scenario 12 of the analysis described in Laúd OPO Network (2020), and presented in their Figure 4.

Simulating *Ex Situ* Leatherback Turtle Management

Upwell science staff and PVA workshop participants identified four categories of *ex situ* management options, with each option targeting eggs as the developmental stage of choice for manipulation. Each of these management alternatives is described in some detail below.

1. Headstarting (HS) – In this alternative, leatherback eggs are collected from natural nests in Mexico or Costa Rica, and transferred to a nearby rearing facility. The eggs are hatched and raised in this facility for approximately three months, which was considered to be a reasonable duration for balancing vigorous growth to a suitable size to avoid at least some predation risk, while also minimizing the negative impacts of the artificial environment such as nutritional or behavioral deficits (e.g., Wyneken, pers. comm.). Individuals are then transported to an appropriate offshore location and released.

   In order for this management alternative to show any potential for improving the status of local subpopulations, the total survival of headstarted individuals to some defined age – for example, one year of age – must be greater than the survival among individuals hatching from natural nests. In consultation with those workshop participants who have direct experience in raising leatherbacks and similar species in artificial conditions, it was decided to include the following target demographic parameters in all HS scenarios:

   - Hatch rate: 50% at the onset of the program, with improvements in husbandry, etc. leading to a linear increase to 75% after five years (Williamson 2018);
   - Hatchlings emerge at the same sex ratio as in natural nests (84% female);
   - Post-hatch survival in rearing facility to three months: 25% at the onset of the program, with improvements in husbandry, etc. leading to a linear increase to 40% after five years;
   - Post-release survival to one year of age increased by 50% relative to hatchlings produced from natural nests.
   - Additionally, we assume that eggs are collected at random for headstarting; in other words, priority is not given to what might be identified as "doomed eggs" that would otherwise die before hatching due to poor nest location, etc.

   Taken together, these targets for successful *ex situ* rearing would result in a 28% increase in the expected production of Age-1 individuals compared to the fully natural state. [For a more detailed discussion of these calculations and underlying assumptions, see Appendix B.] These may indeed be considered ambitious targets, but the present analysis is intended to explore the potential for *ex situ* management – if implemented successfully – to contribute to long-term wild population stability and viability. It is in this spirit of inquiry that this analysis is undertaken. The actual feasibility of achieving these management targets will be addressed elsewhere in this and other reports.

2. Egg Translocation Option A (ET – A) – Leatherback eggs are collected from an unidentified external source, and deposited in artificial nests in Mexico or Costa Rica in hatcheries at existing nesting beaches where they are allowed to incubate and hatch under natural conditions.

   All ET – A scenarios feature the following assumptions:

   - Collection of eggs from an external source will not adversely impact the long-term viability of that population;
   - 95% of all translocated eggs survive transportation from the source to the final nesting beach location;
   - Young individuals added to the subpopulation through translocation will not exhibit adverse behaviors related to navigation, feeding, etc. compared to individuals that hatched from Eastern Pacific beaches;

- Translocated eggs have identical survival to one year of age as those eggs deposited in natural nests on the same beaches.

3. Egg Translocation Option B (ET-B) – Leatherback eggs are collected from an unidentified external source, transported to an egg incubation facility near the recipient destination for hatching, and released to an appropriate location near shore 24-48 hours after hatching.

   All ET – B models assume the following characteristics:

   - Collection of eggs from an external source will not adversely impact the long-term viability of that population;
   - 95% of all translocated eggs survive transportation from the source to the final nesting beach location;
   - Hatch rate: 50% at the onset of the program, with improvements in husbandry, etc. leading to a linear increase to 75% after five years;
   - Hatchlings emerge at the same sex ratio as in natural nests (84% female);
   - Young individuals added to the subpopulation through translocation will not exhibit adverse behaviors related to navigation, feeding, etc. compared to individuals that hatched from Eastern Pacific beaches;
   - Hatchlings produced from translocated eggs have identical survival to one year of age as those hatchlings produced from eggs deposited in natural nests on the same beaches.

4. Egg Translocation Option C (ET-C) – Leatherback eggs are collected from an unidentified external source, and transported to an incubation facility near the recipient destination; eggs are hatched and raised in the rearing facility for three months as in the HS management option; individuals are then released at an appropriate location offshore at three months of age.

   All ET – C models assume the following characteristics:

   - Collection of eggs from an external source will not adversely impact the long-term viability of that population;
   - 95% of all translocated eggs survive transportation from the source to the final nesting beach location;
   - Hatch rate: 50% at the onset of the program, with improvements in husbandry, etc. leading to a linear increase to 75% after five years;
   - Hatchlings emerge at the same sex ratio as in natural nests (84% female);
   - Post-hatch survival to three months: 25% at the onset of the program, with improvements in husbandry, etc. leading to a linear increase to 40% after five years;
   - Post-release survival to one year of age increased by 50% relative to hatchlings produced from natural nests;
   - Young individuals added to the subpopulation through translocation will not exhibit adverse behaviors related to navigation, feeding, etc. compared to individuals that hatched from Eastern Pacific beaches.

Figure 2-3 gives simple deterministic calculations of the expected number of yearling (Age-1) individuals produced in each of the main scenario types considered in this analysis, starting from an arbitrary point of 1000 eggs. Note that the total first-year survival of 0.063 is deconstructed into a monthly survival value of 0.794. This monthly value is then used as the basis for estimating survival of individuals released at three months of age from a headstarting program (HS and ET – C scenarios), with the added assumption of a 50% increase in that survivorship over the nine months between release and one year of age. This cumulative increase translates into a 4.6% increase in monthly survival over the nine-month period under consideration. Also note that the calculations are done once the *ex situ* management programs have matured over a five-year period from their initiation to the stage in which the egg hatching success rate and three-month yearling survival have improved to their maximum values of 0.75 and 0.4, respectively.

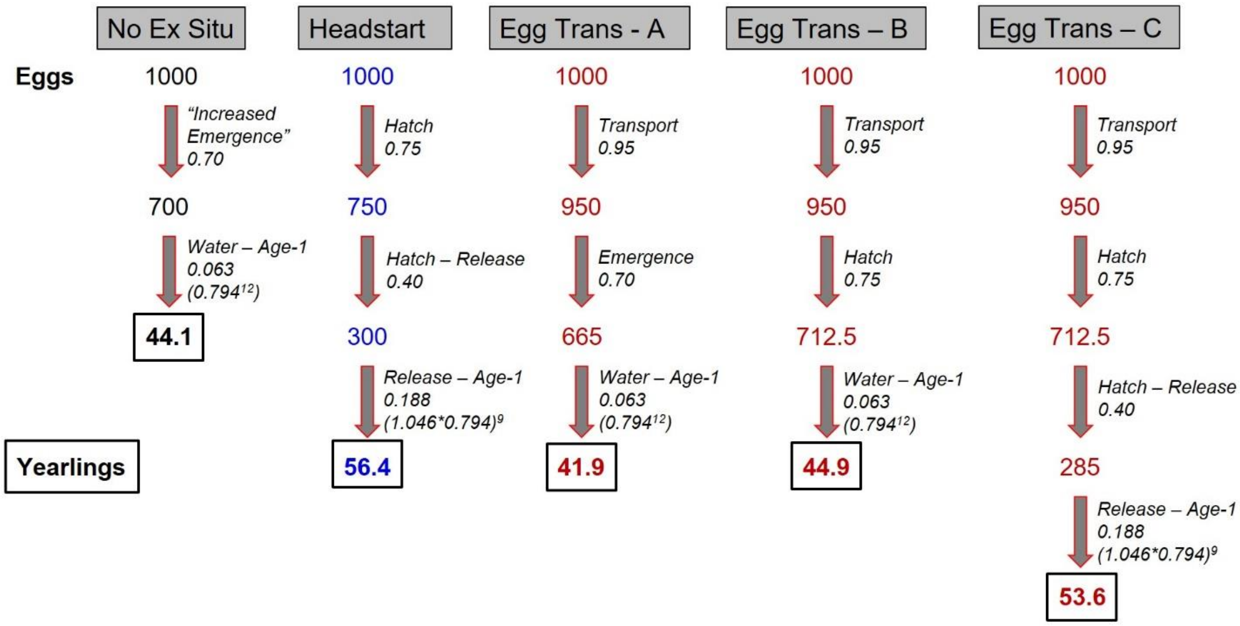


Figure 2-3. Deterministic calculations of expected yearling (Age-1) production (values in boxes) from each of the primary *ex situ* management options evaluated in this analysis, in comparison to the default option without *ex situ* management. Eggs sourced from an external population are identified by red text, while those eggs sourced internally are in blue text. Values next to vertical arrows indicate the survival rates associated with each transition from egg to yearling. See accompanying text for detailed descriptions of each management option.

Each of the four *ex situ* management scenarios were implemented at three levels of intensity, targeting 2000, 4000, or 6000 eggs collected for headstarting or translocation each year of the program. The *ex situ* management program was assumed to start somewhat arbitrarily in model year 3, simulating some time required for program development and planning, and to continue each year for a total of 25 years. In addition, the scenarios apply *ex situ* management efforts to either the Mexico or the Costa Rica population, in order to evaluate the relative viability of each of the subpopulations separately. This yields a total of 25 management scenarios for each of the nine levels of bycatch mortality reduction (including one scenario with no bycatch mortality reduction), resulting in a grand total of 225 unique management scenarios for evaluation and comparison (Figure 2-4).

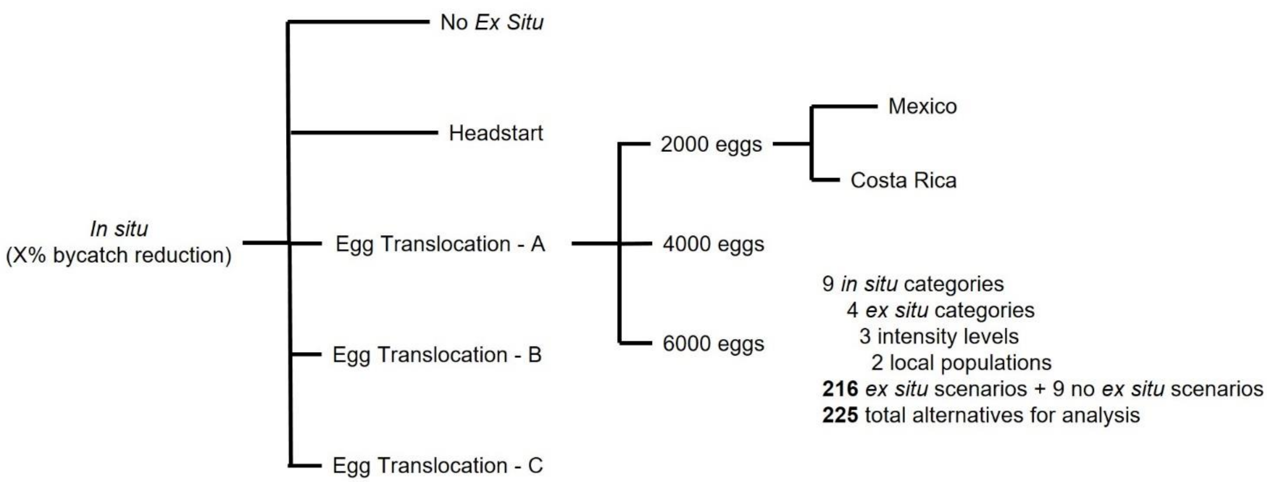


Figure 2-4. PVA model scenario structure. See accompanying text for more details on *in situ* and *ex situ* management options.

A summary of the basic input dataset is shown in Table 2-1. Additional detailed information on model input can be found in the Supplemental Information following this report.

Table 2-1. Summary of demographic data used in Eastern Pacific leatherback PVA models.

Demographic Parameter	Mexico	Costa Rica	Source
Age of first breeding, ♀	12 yrs	12 yrs	Laúd OPO 2020
Maximum age	40 yrs	40 yrs	Upwell PVA Team
Mean Pr[breeding] per year	0.3	0.3	Upwell PVA Team Based on Laúd OPO 2020 estimates of detailed renesting interval data
Eggs/nesting female/year	390	403	Laúd OPO 2020
Sex ratio (prop. female)	0.84	0.84	Laúd OPO 2020
Survival from egg to water	0.47	0.31	Laúd OPO 2020
Hatchlings to water	181	123	Laúd OPO 2020
Annual mortality rate (%)			
First year (from egg)	97.1	98.1	This study (Derived from Laúd OPO 2020)
Juvenile (Age-1 – Age-3)	50.0	50.0	Laúd OPO 2020
Subadult (Age-3 – Age-12)	29.5 24.5	21.2 25.2	Laúd OPO 2020 This study (Modified from above)
Adult (Age-12+)	29.5 24.5	21.2 25.2	Laúd OPO 2020 This study (Modified from above)
Initial abundance (total adult females)	179	54	This study
Carrying capacity (adult females)	8,000	6,000	This study (Based on Laúd OPO 2020)

Results of Simulation Modeling

Retrospective Analysis of Historic Subpopulation Abundance

Before developing prospective models of future leatherback abundance in the presence of the management alternatives discussed in the previous section, we set out to evaluate the extent to which the input data for each subpopulation accurately described past changes in nesting female abundance. This retrospective analysis is a valuable method for properly calibrating initial conditions for the model before it is used for generating predictions of future subpopulation dynamics. To conduct this analysis, input data for each subpopulation summarized in Table 2-1 were used to create retrospective models of nesting female abundances beginning in the year 1988 and moving forward through time until 2018. Initial abundance values were adjusted to correspond to the nesting female counts reported for 1988 in Laúd OPO Network (2020).

Projections using the raw input data derived from Laúd OPO Network (2020) resulted in some deviations in predicted nesting female abundance from the observed data, especially for the Costa Rica subpopulation (Figure 2-5). The Mexico subpopulation model agreed rather well with the observed nesting data in the earlier years of the dataset, although there is a higher level of divergence in abundance for the more recent portion of the observations. In contrast, the Costa Rica subpopulation projection using the raw input dataset resulted in a considerable overestimate of nesting female abundance across the full time period of analysis, particularly in the more recent years of observations.

In light of these results, an alternative view of subpopulation growth was proposed in which the demographic rates changed over the course of the period of observation. For the Costa Rica subpopulation, it has been documented that hatchling production on index beaches was almost negligible before 1995, at which time significant improvements were made to nest protection, leading to dramatic reductions in egg poaching going forward (Santidrián Tomillo et al. 2007). Incorporating this information into our retrospective model of Costa Rica subpopulation dynamics led to a significant improvement in agreement between observed and predicted abundance estimates. Additionally, a small revision to subadult and adult mortality rate was included in the revised Costa Rica retrospective model at model year 2006, leading to a more realistic portrayal of past population decline (Figure 5, bottom right). While a significant modification of hatchling production was not necessary to generate better alignment of the Mexico retrospective model, a similar modification was made to subadult and adult survival rates after model year 2006 in order to improve the agreement between observed and predicted abundance estimates. The revised estimates of subadult and adult mortality for each subpopulation are summarized in Table 2-1.

Note that the retrospective model prediction for the Mexico subpopulation does not account mechanistically for the marked increase in nesting female abundance during the time period 2014 – 2016. As a result, the final abundance predicted by the model is slightly lower than that observed in the final year of observation (2018). Discussion of these data amongst local species experts in the PVA workshop sessions revealed that the observed transient increase in abundance was likely neither a direct response to past management activities, nor a result of previous environmental factors generally predicted to support leatherback population growth. Consequently, the observed increase was most likely a product of past stochastic variability in demographics that occur from time to time over the course of unpredictable population growth and decline. The group also noted that preliminary survey efforts indicate very few females observed to be nesting on Mexico index beaches in the past 1 – 2 years, thus yielding closer agreement between observed and predicted abundances.

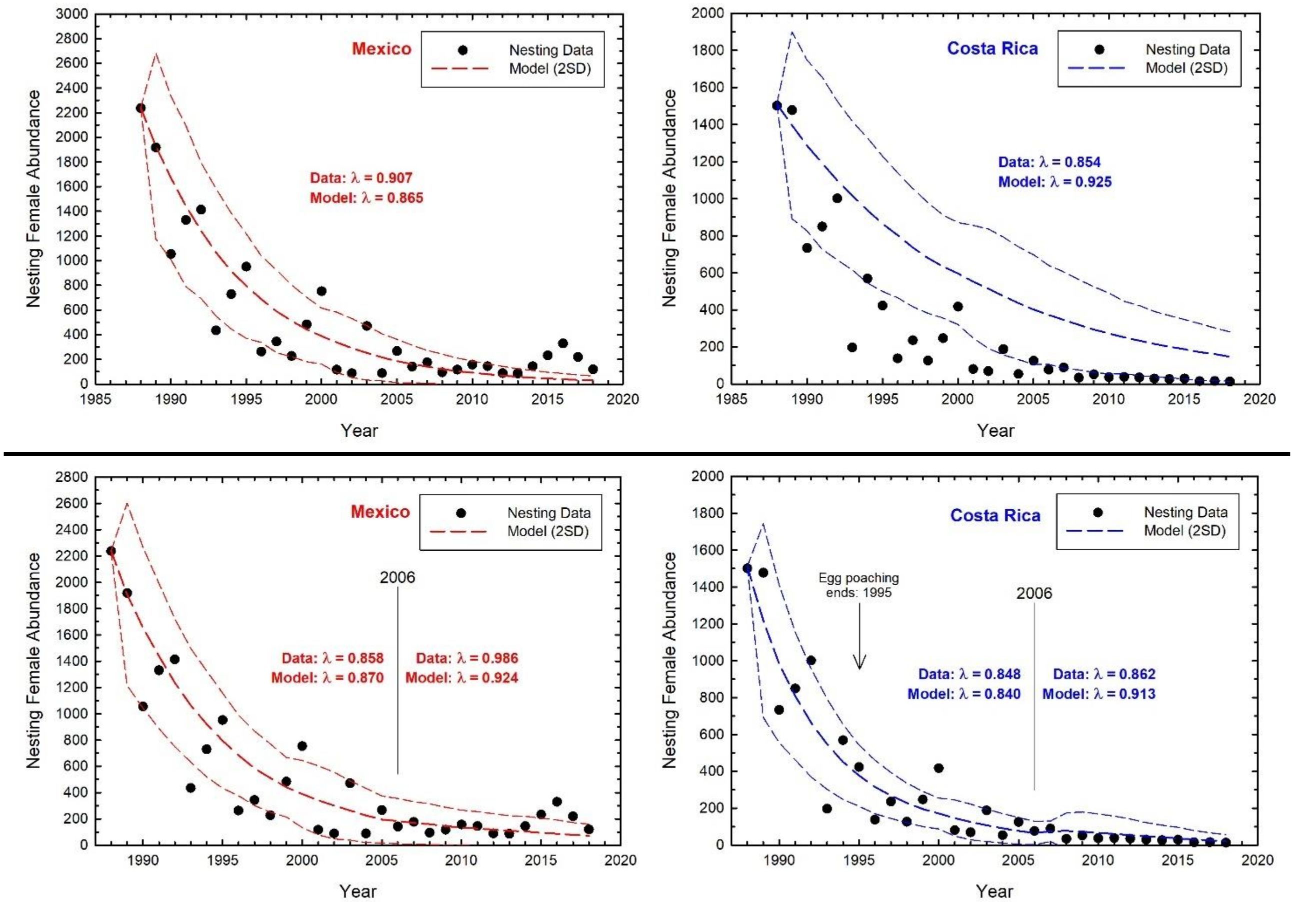


Figure 2-5. Retrospective projections of nesting female abundance (mean ± 2SD) on index beaches of Mexico (left half, red) and Costa Rica (right half, blue). Top half of the figure shows abundance projections using the unmodified survival data of Laúd OPO Network (2020); bottom half of the figure shows revised projections using modified subpopulation-specific estimates of subadult and adult survival rate derived from this analysis. The revised model for Costa Rica also includes a modification to hatchling production in the model year 1995. Annual growth rate estimates (λ) are calculated directly from observed abundance data or from mean annual abundance values derived from model projections. See accompanying text for more information on retrospective model parameters and structure.

Finally, it is important to note that the retrospective analysis described here is not intended to be a rigorous statistical comparison of observed and predicted abundances. Instead, the goal is to develop demographic models of satisfactory realism and accuracy that can serve as starting points for prospective comparisons of population response to a broad suite of population management alternatives. In particular, it is critical to recognize that we seek to make relative comparisons of population performance in this analysis, without claiming to make sweeping predictions of future population abundance based on interpretation of absolute model outcomes. In that regard, the value of the analysis does not depend on identifying the precise starting point with inarguable statistical accuracy. Nevertheless, our models now successfully replicate the steady decline in nesting female abundance in both Mexico and Costa Rica, the smaller abundance of leatherback turtles in Costa Rica and the comparatively more rapid decline in that subpopulation's nesting females. Consequently, we can be confident that our comparative analysis of both *in situ* and *ex situ* management options is based on a credible description of current leatherback turtle population dynamics.

No Changes to Current Management: Status Quo Projections

If we assume that current management activities do not change in the future, our models predicted that both the Mexico and Costa Rica subpopulations will continue to decline at the observed rates (Figure 2-6). The expected number of nesting females in Costa Rica is likely to drop to less than five individuals within approximately 12 years (i.e., the year 2032), while the number in the Mexico subpopulation is likely to decline to similar levels in about 25 years (i.e., the year 2045). The probability of the subpopulations continuing to persist began to decline between years 15 and 25 for Costa Rica and Mexico, respectively. At model year 30, the likelihood of Costa Rica subpopulation persistence decreased to approximately 0.55, which is considerably lower than the corresponding likelihood for Mexico (0.95). By model year 60, both subpopulations show a very high risk of local extinction (probability of persistence less than 0.05). The likelihood of total metapopulation persistence (not shown in Figure 2-6) tracks closely with that for the larger and comparatively more secure Mexico subpopulation, with the likelihood declining to 0.50 in model year 43 and declining further to 0.02 by the end of the 60-year simulation.

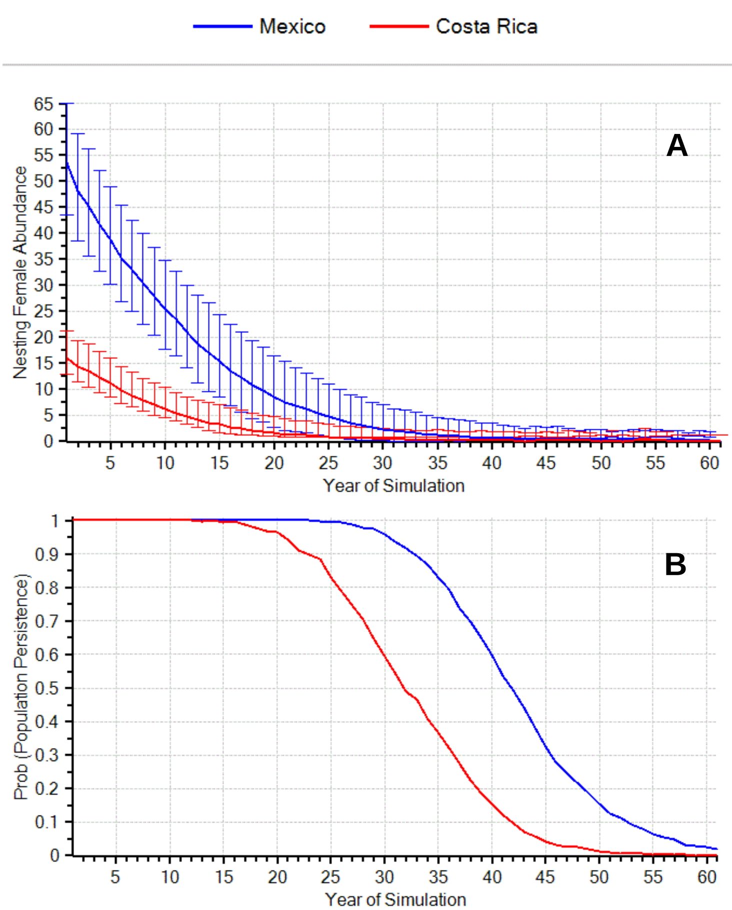


Figure 2-6. Mean ± 1SD of nesting female abundance (A, top) and probability of population persistence (B, bottom) for the Mexico and Costa Rica subpopulations under the assumption of no change in current management practices, i.e., status quo.

The mean growth rates (λ) from the status quo model were 0.869 for Mexico and 0.862 for Costa Rica, indicating a slightly more rapid rate of decline for the smaller Costa Rica subpopulation. The growth rate for the combined metapopulation was calculated as 0.866, which aligns quite closely to that calculated for the status quo model (λ = 0.864) described in Laúd OPO Network (2020). This outcome provides additional evidence for proper incorporation of input data and overall biological process elements from the original published modeling effort into the current analysis.

Predicted Impacts of *In Situ* Management

Reducing subadult and adult leatherback mortality through mitigating fisheries bycatch interactions arrested the rate of subpopulation decline in both Mexico and Costa Rica, but comparatively aggressive mitigation appeared to be necessary to facilitate sustained increases in nesting female abundance (Figures 2-7, 2-8). Since leatherback females must survive for at least 12 years before becoming reproductively active, the impacts of both improved nest protection and survival of older age classes were not noticeable for at least a decade after the onset of the simulation. Sustained subpopulation growth in Mexico was achieved when the extent of bycatch mortality mitigation reaches 30%. This translates into mean subadult and adult mortality being reduced from the status quo value of 0.245 to 0.1715. In terms of survival, this level of bycatch mortality mitigation is equivalent to a 9.7% increase in survival, from the status quo value of 0.755 to the improved value of 0.8285.

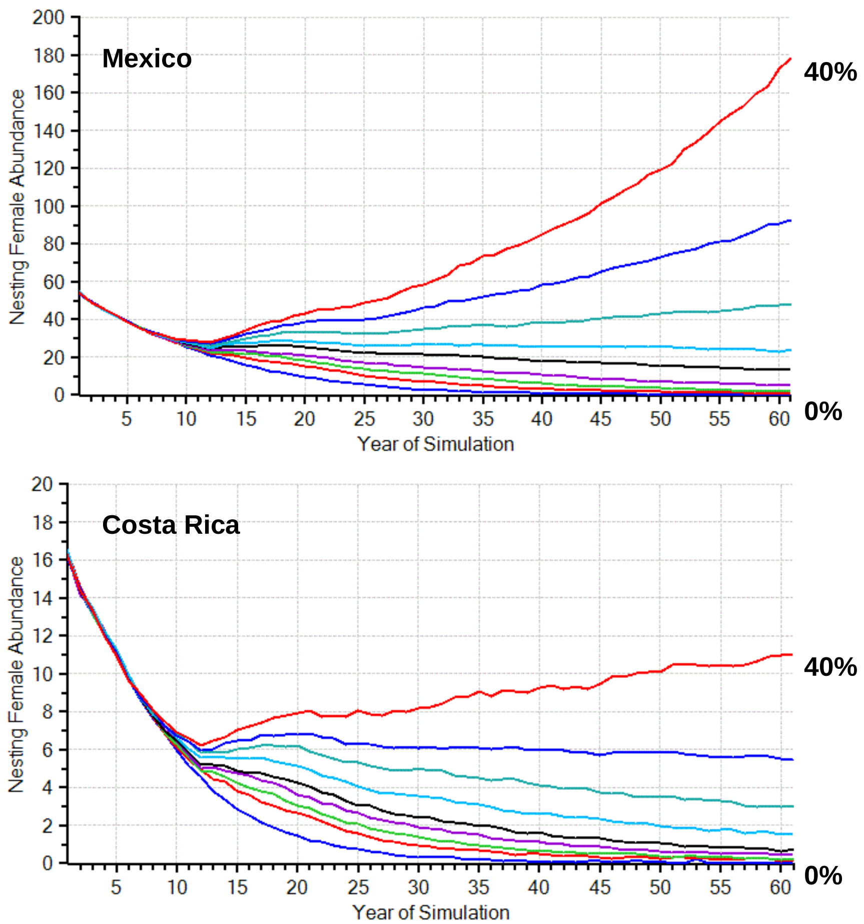
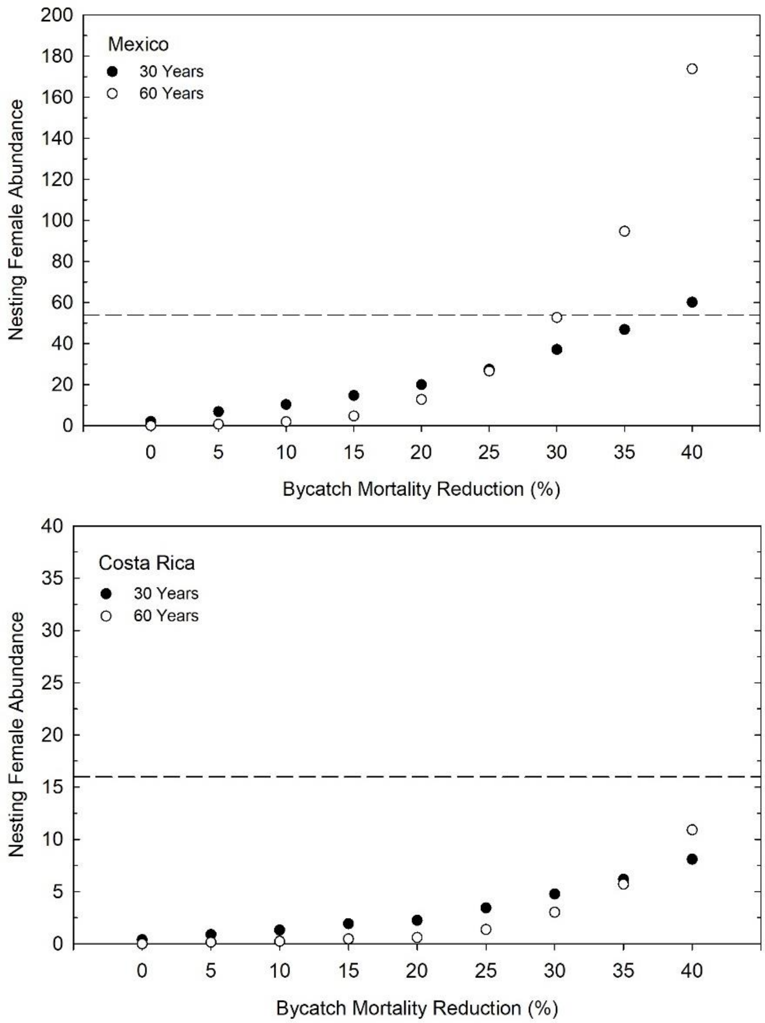


Figure 2-7. Mean nesting female abundance for the Mexico and Costa Rica subpopulations with the inclusion of different levels of *in situ* management (incremental increases in fisheries bycatch mortality mitigation). End points for the range of bycatch mitigation are given on the right side of each panel, with each colored trajectory representing a 5% incremental increase in bycatch mortality reduction from bottom to top of the plot. See text for additional details on model structure and implementation.

Note, however, that this threshold target of 30% bycatch mortality mitigation was successful only at bringing the mean nesting female abundance among Mexico beaches back up to its initial value of 54 individuals after 60 years of the simulation (Figure 2-8). Higher levels of bycatch mitigation (i.e., 40% reduction) led to comparatively substantial subpopulation growth, with nearly 180 nesting females at year 60. In stark contrast to the predictions for Mexico, the Costa Rica subpopulation failed to return to the initial abundance of nesting females even with the most aggressive level of bycatch mortality mitigation tested here. The scenario featuring 40% bycatch mortality mitigation led to a final mean nesting female abundance of 10.9 individuals, just 68% of the original value of 16 nesting females.

Figure 2-8. Mean nesting female abundance for the Mexico (top panel) and Costa Rica (bottom panel) subpopulations at model years 30 (black circles) and 60 (white circles), with the inclusion of different levels of *in situ* management (incremental increases in fisheries bycatch mortality mitigation). Horizontal dashed lines indicate the initial abundance of nesting females in each subpopulation. See text for additional details on model structure and implementation.



Lower levels of fisheries bycatch mortality mitigation led to significant improvements in the likelihood of subpopulation persistence, particularly in the longer term for Mexico and across both short- and long-term timeframes for Costa Rica (Figure 2-9). Extinction risk for the Mexico subpopulation at 60 years was essentially eliminated when bycatch mortality was reduced by 20% or more, although steep declines in risk are evident with lower levels of mitigation effort. Higher levels of mortality mitigation – above 30% -- were required to improve the long-term likelihood of persistence above 0.90 for the Costa Rica subpopulation. If mitigation were less successful for this subpopulation, persistence probabilities over the longer time horizon also dropped dramatically.

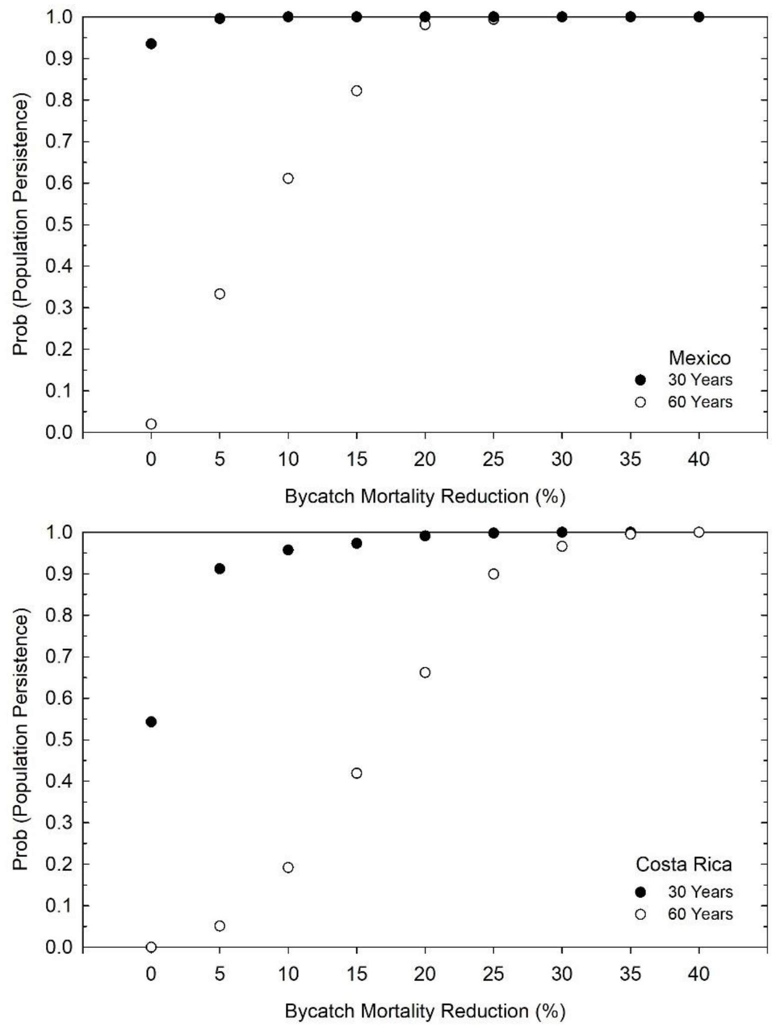


Figure 2-9. Probability of persistence for the Mexico (top panel) and Costa Rica (bottom panel) subpopulations at model years 30 (black circles) and 60 (white circles), with the inclusion of different levels of *in situ* management (incremental increases in fisheries bycatch mortality mitigation). See text for additional details on model structure and implementation.

Analysis of *Ex Situ* Management Benefits

Figure 2-10 shows a representative sample of scenarios featuring a single level of bycatch mortality mitigation (25%) and including the range of *ex situ* management options implemented at varying levels of intensity in either Mexico or Costa Rica. Under this level of bycatch mortality mitigation, the long-term nesting female abundance in Mexico remained quite stable at approximately 26-27 individuals, indicating some level of equilibrium between removal of females through bycatch and addition of new adult females through recruitment of younger turtles. The addition of a headstarting program (HS) to the Mexico subpopulation led to small increases in long-term nesting female abundance, of just two to four individuals after 60 years depending on the intensity of the headstarting effort. Egg translocation efforts led to more pronounced increases in nesting female abundance, with the highest level of effort (6000 eggs translocated annually) resulting in a nearly 75% increase in nesting female abundance at model year 60. Note that the long-term abundance was slightly lower than the maximum value achieved about 12 years after cessation of the headstarting program (model year 39), at which time the increased level of recruitment dropped off in response to the absence of translocated turtles entering the system.

The Costa Rica subpopulation derived even greater short-term benefit from the various *ex situ* management options, with the maximum nesting female abundance at model year 39 increasing 8-fold relative to the scenario featuring only *in situ* management activities. However, because of the less favorable underlying demographics previously observed in this smaller, unstable subpopulation, the benefits of *ex situ* management were quickly erased in the later years of the simulation, after the *ex situ* management activities were halted at model year 27. Despite this erosion of nesting female abundance, the number of nesting females in the Costa Rica subpopulation at the end of the simulation remained up to about five times larger (for the highest level of egg translocation management) than the scenario restricted to *in situ* management only.

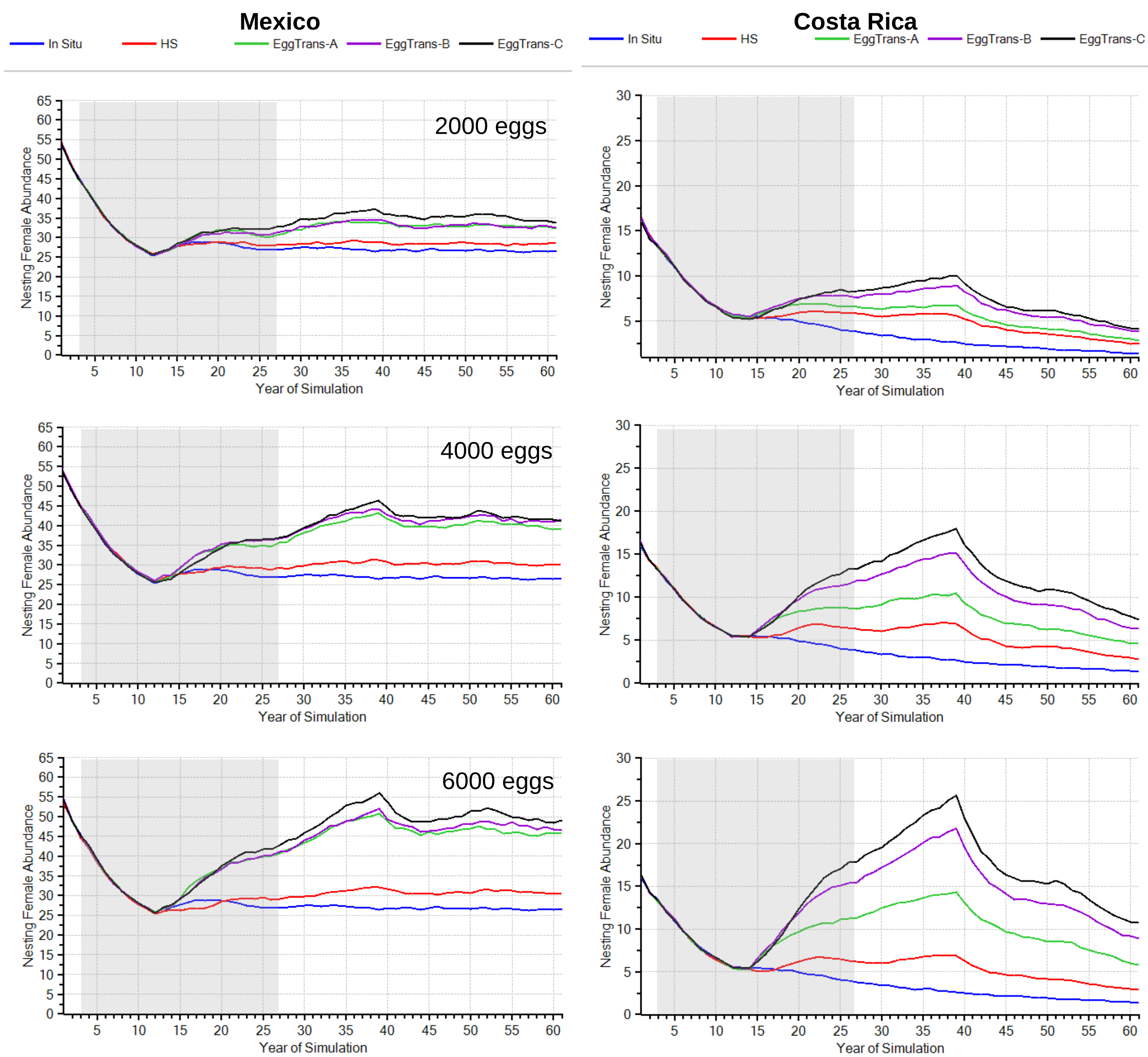


Figure 2-10. Trajectories of simulated nesting female abundance for the Mexico (left panel) and Costa Rica (right panel) subpopulations, assuming a 25% fisheries bycatch mortality mitigation scenario and including the implementation of the range of *ex situ* management options. *In situ*, increased emergence and bycatch mortality mitigation only; HS, headstarting program; EggTrans-A, egg translocation type-A program; EggTrans-B, egg translocation type-B program; EggTrans-C, egg translocation type-C program. Rows of panels are differentiated by the intensity of proposed *ex situ* management, defined as the number of leatherback eggs collected each year during the 25-year duration of the simulated management program. Time period of active *ex situ* management highlighted with gray shading. See text for additional information on model structure and *ex situ* management details.

<u>An evaluation of model sensitivity to *ex situ* management assumptions</u>

The final outcome of any management scenario – involving *in situ* or *ex situ* components – will be highly dependent on the suitability of the assumptions built into its development. It is wise to explore at least some of what are considered to be those assumptions with the greatest level of uncertainty, so that we can test the potential impacts of our incomplete knowledge of the system that is being managed.

As an example of this exercise, we tested the implications of uncertainty in a key element of both the headstarting (HS) and egg translocation type-C (ET-C) *ex situ* management options: the rate of survival to one year (Age-1) following release of 3-month-old individuals maintained in *ex situ* facilities after collection from local nests (HS) or after translocation from an external source beach (ET-C). Our initial assumption was that individuals successfully raised in *ex situ* facilities would display a 50% increase in total survival from release at three months to one year of age, in comparison to yearling turtles that hatch from natural nests. Additional scenarios were constructed that included alternative assumptions about that rate of survival:

- 25% total increase in post-release survival to Age-1;
- No increase in post-release survival to Age-1;
- 25% total decrease in post-release survival to Age-1.

We ran these sensitivity scenarios assuming a 25% fisheries bycatch mortality mitigation effort, and applied the two alternative *ex situ* management scenarios to the Mexico subpopulation. The results of this analysis are expected to be qualitatively similar if they were to be applied to the Costa Rica subpopulation.

The results of this analysis are summarized in Figure 2-11. In the headstarting (HS) management scenario, mean nesting female abundance was increased over the bycatch mortality mitigation scenario only under the most optimistic assumption of post-release survival rate. Even under this most generous assumption, the mean nesting female abundance in the *ex situ* scenario was increased by only two to three individuals after the full duration of the simulation. If post-release survival to Age-1 following headstarting were increased by 25% relative to wild-hatched yearlings, the mean nesting female abundance was unchanged. Furthermore, if post-release survival of headstarted individuals were assumed to be no better or 25% worse than wild-hatched yearlings, mean nesting female abundance decreased compared to implementing only *in situ* management activities.

When leatherback eggs were translocated from an external source, then hatched and raised in *ex situ* facilities to three months of age, uncertainty in our assumption regarding post-release survival of released individuals also led to similar variability in the model projections of nesting female abundance. However, the expected nesting female abundance was always greater than the scenario featuring only *in situ* management – even when post-release survival was assumed to be lower than yearlings that hatch in natural nests. Under the least favorable assumption of 25% lower post-release survival compared to wild-hatched yearlings, the final nesting female abundance was 29% greater than the scenario featuring only *in situ* management activities. When post-release survival of individuals in the ET-C *ex situ* management scenario was assumed to be equal to their wild-hatched yearling counterparts, the final nesting female abundance increased to 39% greater than the scenario featuring only *in situ* management.

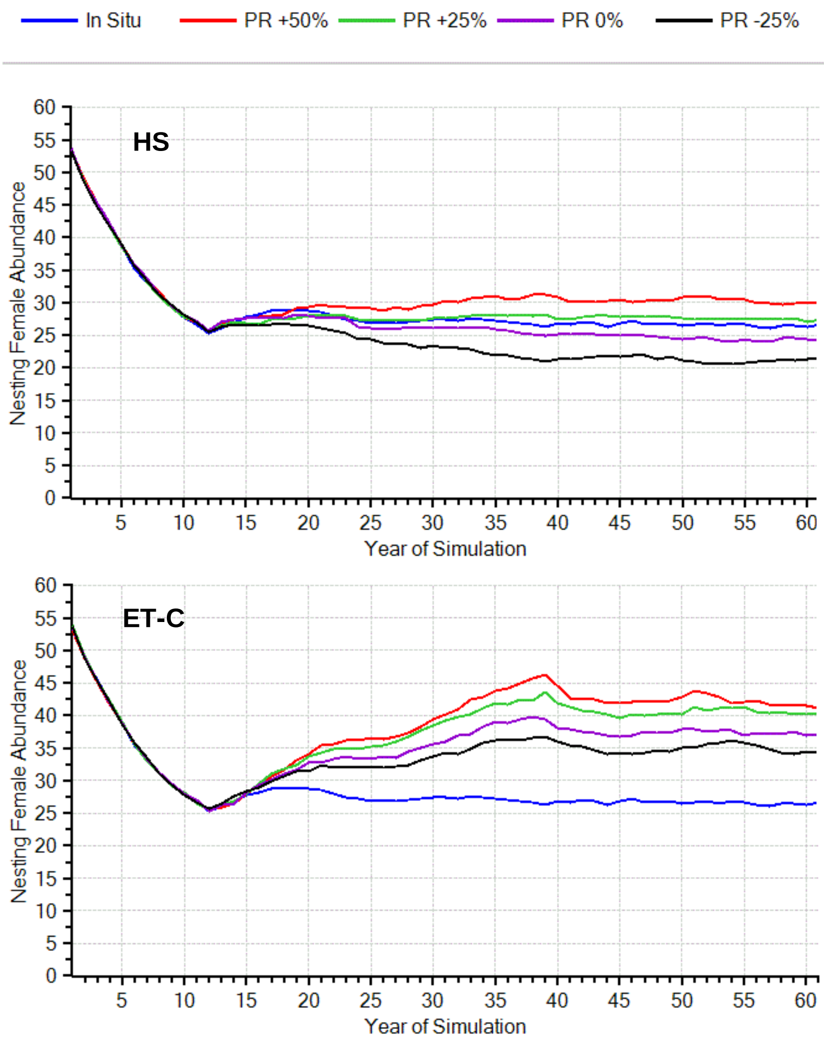


Figure 2-11. Results of sensitivity analysis of post-release (PR) survival rate in headstarting (HS) and egg translocation type-C (ET-C) *ex situ* management options. Individual trajectories are defined by the extent of assumed difference in post-release survival of young turtles managed in *ex situ* facilities, from a 50% increase in total survival (PR +50%) to a 25% decrease in survival (PR -25%). *Ex situ* management scenarios are presented along with the baseline scenario featuring only *in situ* management (increased emergence and bycatch mortality mitigation). See text for additional details on model structure and implementation.

Summary of *Ex Situ* Management Impacts

Model predictions of mean nesting female abundance and probability of persistence for the Mexico and Costa Rica subpopulations across all combinations of *in situ* and *ex situ* management options are summarized graphically in Figure 2-12 – 2-18, and in detailed tabular form in Appendix C. The graphical results are displayed at model years 30 and 60, thereby providing insights into simulated subpopulation behavior at intermediate and long-term time horizons.

While acknowledging the various assumptions regarding model structure and input data discussed previously, inspection of these results provides the following observations:

- When *in situ* management activities were implemented at relatively low levels (bycatch mortality mitigation ≤ 20%), additional increases in nesting female abundance through *ex situ* management of the Mexico subpopulation were only modest across at both 30 years (Figure 2-12) and 60 years (Figure 2-13). Increases in abundance were more pronounced when implementing *ex situ* management at higher levels of bycatch mortality mitigation (≥25%). As expected, additional implementation of *ex situ* management at greater levels of bycatch mortality mitigation produced larger gains in nesting female abundance across longer timeframes (Figure 2-13).

- A headstart (HS) option using eggs collected from local beaches appeared to provide the least benefit to each of the subpopulations, in terms of nesting female abundance across the range of tested intensities. For the Mexico subpopulation, egg translocation type-A and type-B scenarios provided roughly equal benefit at a markedly higher level than HS scenarios, while the egg translocation type – C scenarios, featuring both egg translocation and additional rearing of hatchlings in *ex situ* facilities before release (similar to the HS option), provided the greatest relative benefit to intermediate and longer-term abundance of nesting females.

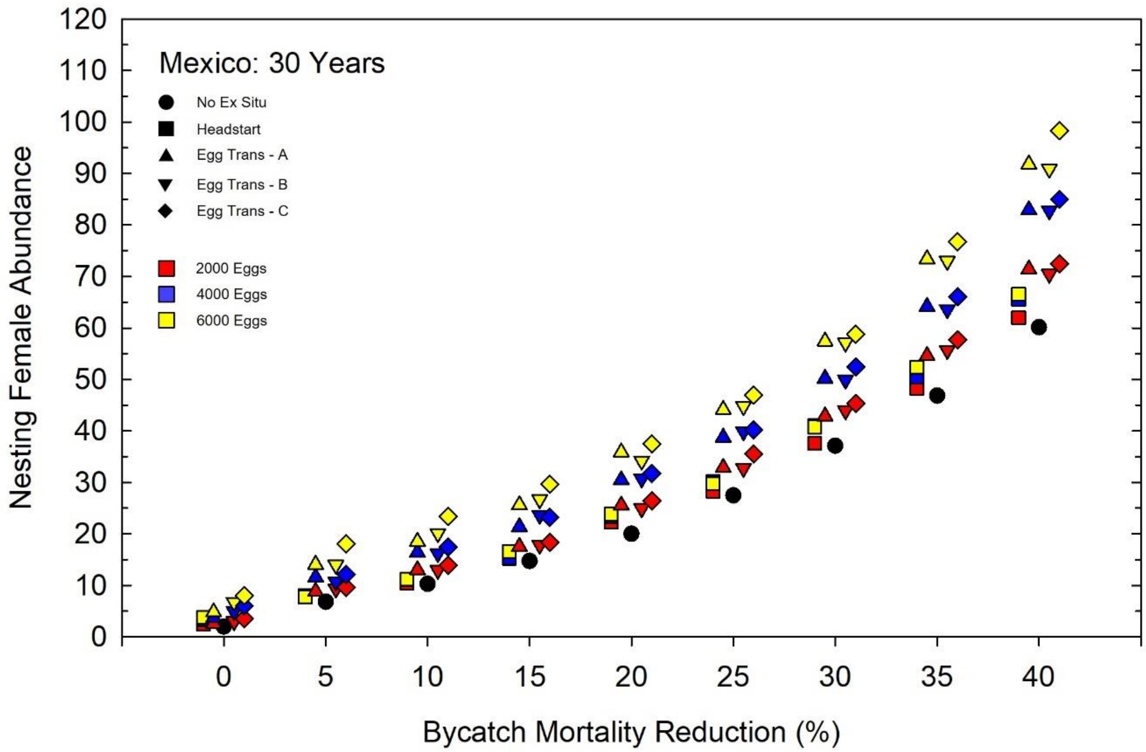


Figure 2-12. Model predictions of mean nesting female abundance in the Mexico subpopulation at year 30 under the range of *in situ* and *ex situ* management scenarios. Scenarios featuring only *in situ* management (including increased hatchling emergence through nesting beach protection and reduced subadult and adult mortality through fisheries bycatch mitigation) are denoted by black circles. Scenarios featuring the additional implementation of a given *ex situ* management option are denoted by one of the distinct symbols identified in the figure legend. The level of implementation effort for a given *ex situ* management option (defined by the number of eggs collected each year for management) is denoted by one of the three colors identified in the figure legend. Each management scenario is therefore defined by a specific symbol-color combination. For example, a headstarting (HS) management option that collects 2000 eggs each year for the duration of that program is represented by a red square, while a yellow diamond represents the collection of 6000 eggs annually for the egg translocation type – C (ET-C) management option. Within each category of bycatch mortality mitigation, the symbols representing management scenarios have been jittered horizontally for easier reading. See accompanying text for additional details on model structure and implementation.

- Across the full duration of the simulation, intermediate and high levels of egg translocation management effort (4000 – 6000 eggs) resulted in substantial increases in the probability of persistence of the Mexico subpopulation, even at very low levels of bycatch mortality mitigation effort (Figure 2-14). Under the highest level of effort for the ET-C management option, the risk of local subpopulation extinction after 60 years was almost eliminated. [Note that persistence probability data for the Mexico subpopulation under *ex situ* management at 30 years are not shown here, owing to the very high probability of persistence of this subpopulation when bycatch mortality mitigation was included (Figure 2-9).]

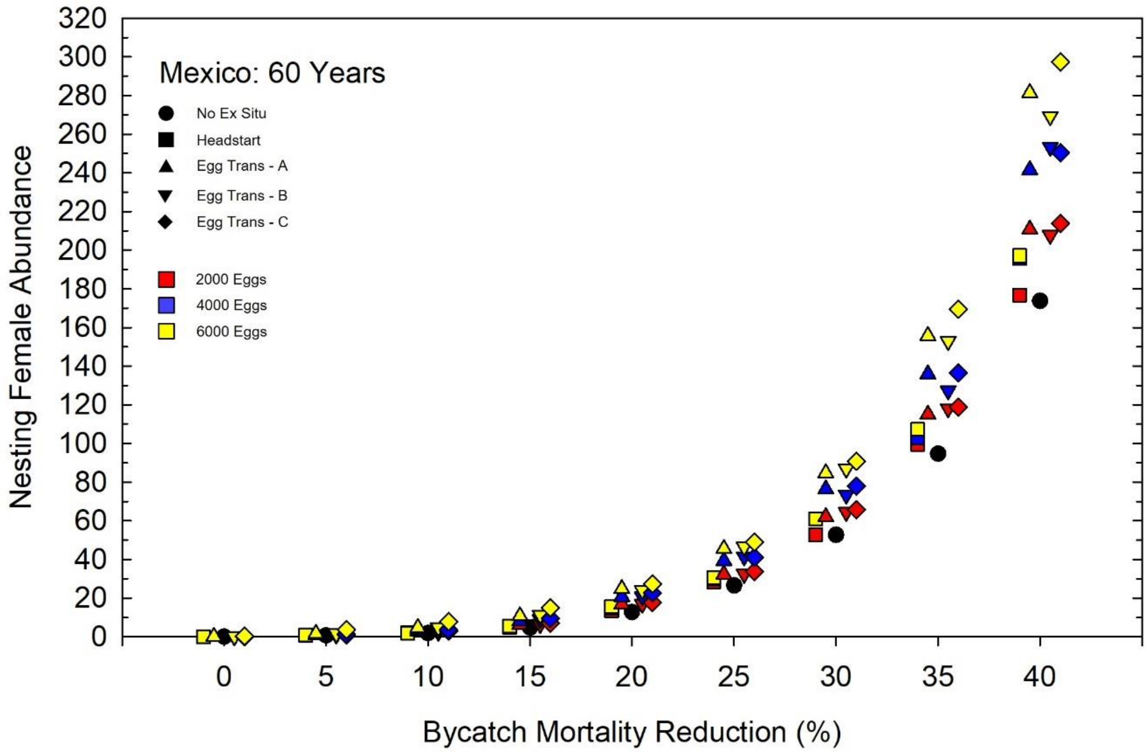


Figure 2-13. Model predictions of mean nesting female abundance in the Mexico subpopulation at year 60 under the range of *in situ* and *ex situ* management scenarios. Scenarios featuring only *in situ* management (including increased hatchling emergence through nesting beach protection and reduced subadult and adult mortality through fisheries bycatch mitigation) are denoted by black circles. Scenarios featuring the additional implementation of a given *ex situ* management option are denoted by one of the distinct symbols identified in the figure legend. The level of implementation effort for a given *ex situ* management option (defined by the number of eggs collected each year for management) is denoted by one of the three colors identified in the figure legend. Each management scenario is therefore defined by a specific symbol-color combination. For example, a headstarting (HS) management option that collects 2000 eggs each year for the duration of that program is represented by a red square, while a yellow diamond represents the collection of 6000 eggs annually for the egg translocation type – C (ET-C) management option. Within each category of bycatch mortality mitigation, the symbols representing management scenarios have been jittered horizontally for easier reading. See accompanying text for additional details on model structure and implementation.

- Applying the same level of *ex situ* management intensity to the smaller Costa Rica subpopulation led to larger proportional increases in nesting female abundance over time relative to the results observed for the Mexico subpopulation (Figures 2-15, 2-16). This outcome is largely a result of the very small number of nesting females present in the population before *ex situ* management were to be implemented. Once again, headstarting (HS) options appeared to provide relatively little numerical benefit to abundance, while egg translocation options led to larger gains.

Note that when applying headstarting scenarios to the Costa Rica subpopulation, model results (not shown here but available on request) revealed that collecting the full complement of eggs targeted for *ex situ* management was not possible in specific model years, owing to random variability in the number of females nesting in that year. In those situations, the model would attempt to collect all the eggs deposited on the nesting beaches, which may not be possible or desirable in reality due to logistical or regulatory constraints.

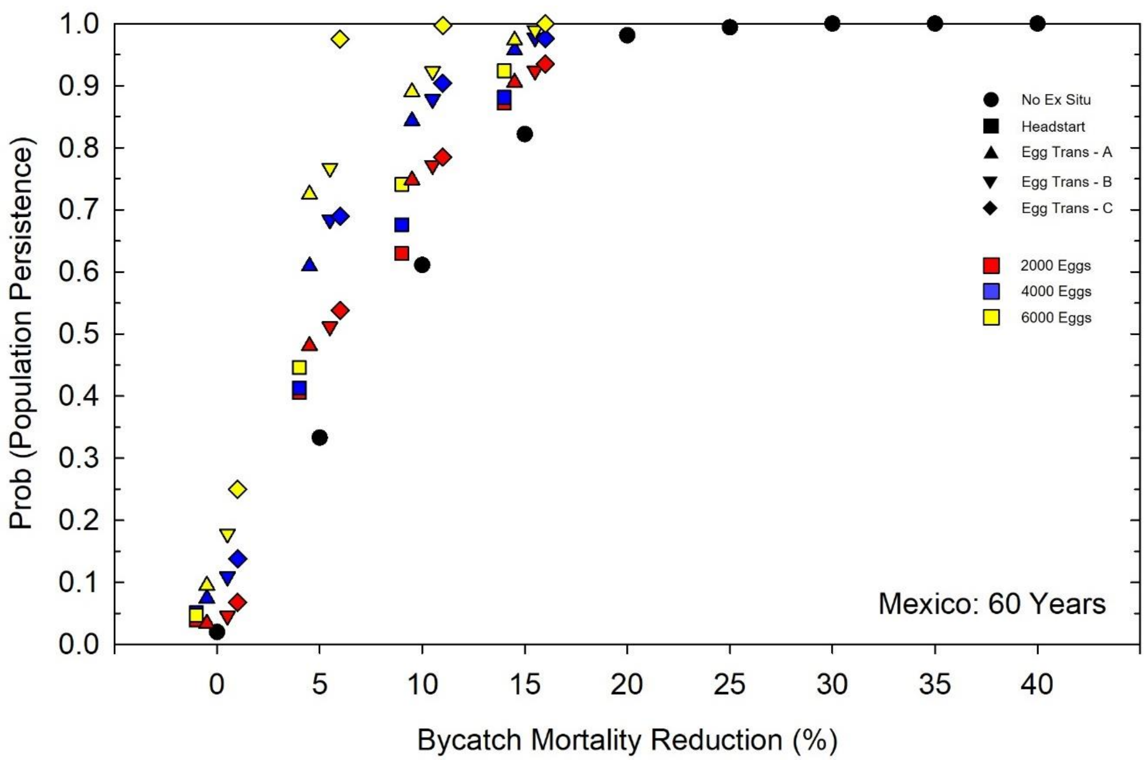


Figure 2-14. Model predictions of probability of persistence of the Mexico subpopulation at year 60 under the range of *in situ* and *ex situ* management scenarios. Scenarios featuring only *in situ* management (including increased hatchling emergence through nesting beach protection and reduced subadult and adult mortality through fisheries bycatch mitigation) are denoted by black circles. Scenarios featuring the additional implementation of a given *ex situ* management option are denoted by one of the distinct symbols identified in the figure legend. The level of implementation effort for a given *ex situ* management option (defined by the number of eggs collected each year for management) is denoted by one of the three colors identified in the figure legend. Each management scenario is therefore defined by a specific symbol-color combination. For example, a headstarting (HS) management option that collects 2000 eggs each year for the duration of that program is represented by a red square, while a yellow diamond represents the collection of 6000 eggs annually for the egg translocation type – C (ET-C) management option. Within each category of bycatch mortality mitigation, the symbols representing management scenarios have been jittered horizontally for easier reading. See accompanying text for additional details on model structure and implementation.

- Implementing any of the *ex situ* management options – even at relatively low levels of intensity – significantly increased the likelihood of persistence of the Costa Rica subpopulation after 30 years when additional *in situ* management activity was not implemented (Figure 2-17). After 60 years, *ex situ* management options significantly improved the probability of persistence for the Costa Rica subpopulation, particularly at lower levels of additional bycatch mortality mitigation (Figure 2-18).

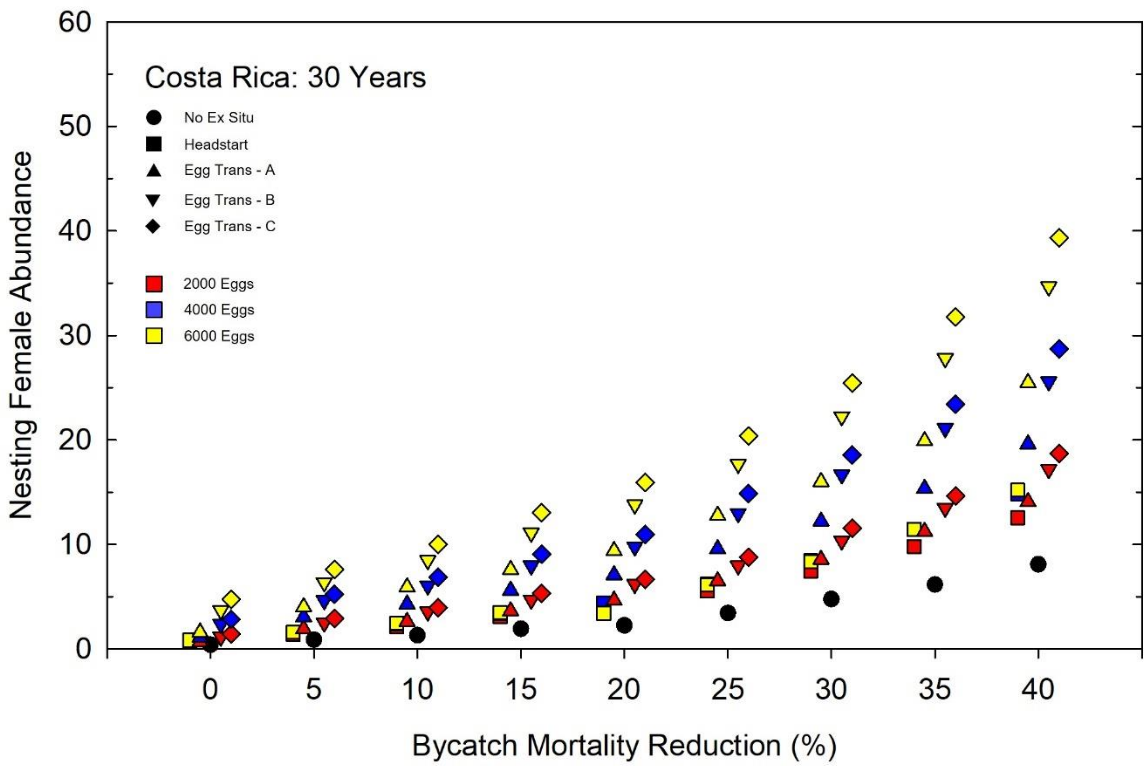


Figure 2-15. Model predictions of mean nesting female abundance in the Costa Rica subpopulation at year 30 under the range of *in situ* and *ex situ* management scenarios. Scenarios featuring only *in situ* management (including increased hatchling emergence through nesting beach protection and reduced subadult and adult mortality through fisheries bycatch mitigation) are denoted by black circles. Scenarios featuring the additional implementation of a given *ex situ* management option are denoted by one of the distinct symbols identified in the figure legend. The level of implementation effort for a given *ex situ* management option (defined by the number of eggs collected each year for management) is denoted by one of the three colors identified in the figure legend. Each management scenario is therefore defined by a specific symbol-color combination. For example, a headstarting (HS) management option that collects 2000 eggs each year for the duration of that program is represented by a red square, while a yellow diamond represents the collection of 6000 eggs annually for the egg translocation type – C (ET-C) management option. Within each category of bycatch mortality mitigation, the symbols representing management scenarios have been jittered horizontally for easier reading. See accompanying text for additional details on model structure and implementation.

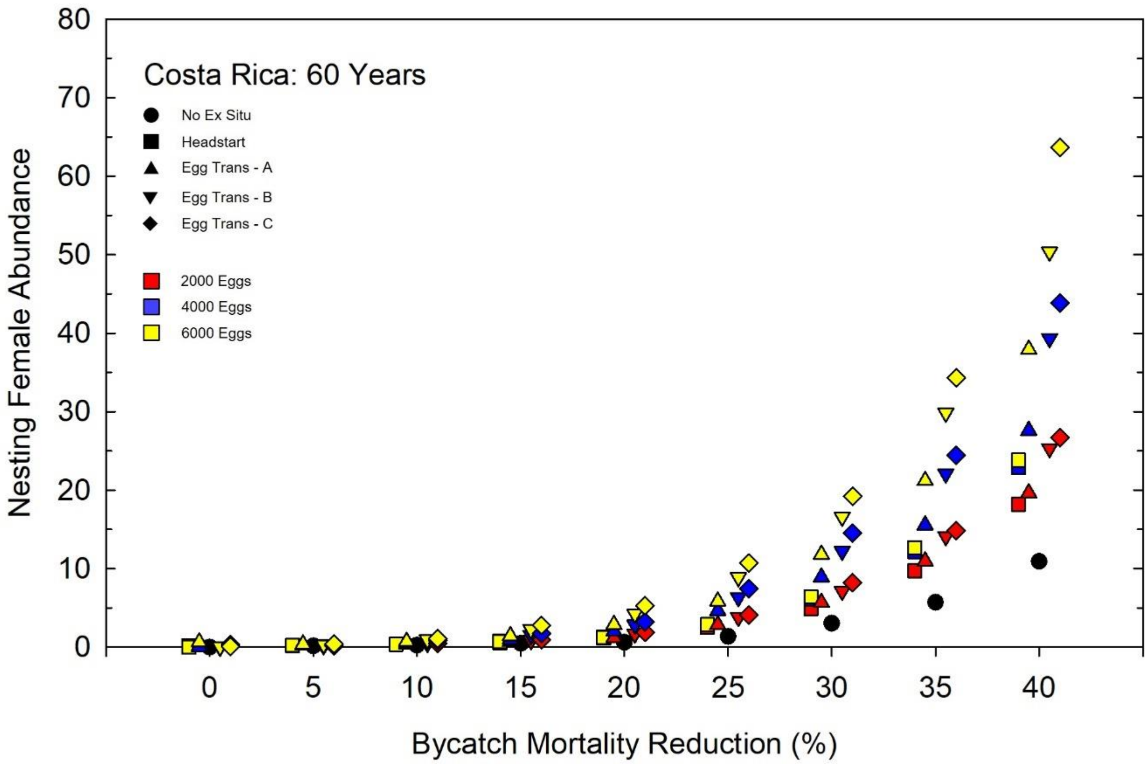


Figure 2-16. Model predictions of mean nesting female abundance in the Costa Rica subpopulation at year 60 under the range of *in situ* and *ex situ* management scenarios. Scenarios featuring only *in situ* management (including increased hatchling emergence through nesting beach protection and reduced subadult and adult mortality through fisheries bycatch mitigation) are denoted by black circles. Scenarios featuring the additional implementation of a given *ex situ* management option are denoted by one of the distinct symbols identified in the figure legend. The level of implementation effort for a given *ex situ* management option (defined by the number of eggs collected each year for management) is denoted by one of the three colors identified in the figure legend. Each management scenario is therefore defined by a specific symbol-color combination. For example, a headstarting (HS) management option that collects 2000 eggs each year for the duration of that program is represented by a red square, while a yellow diamond represents the collection of 6000 eggs annually for the egg translocation type – C (ET-C) management option. Within each category of bycatch mortality mitigation, the symbols representing management scenarios have been jittered horizontally for easier reading. See accompanying text for additional details on model structure and implementation.

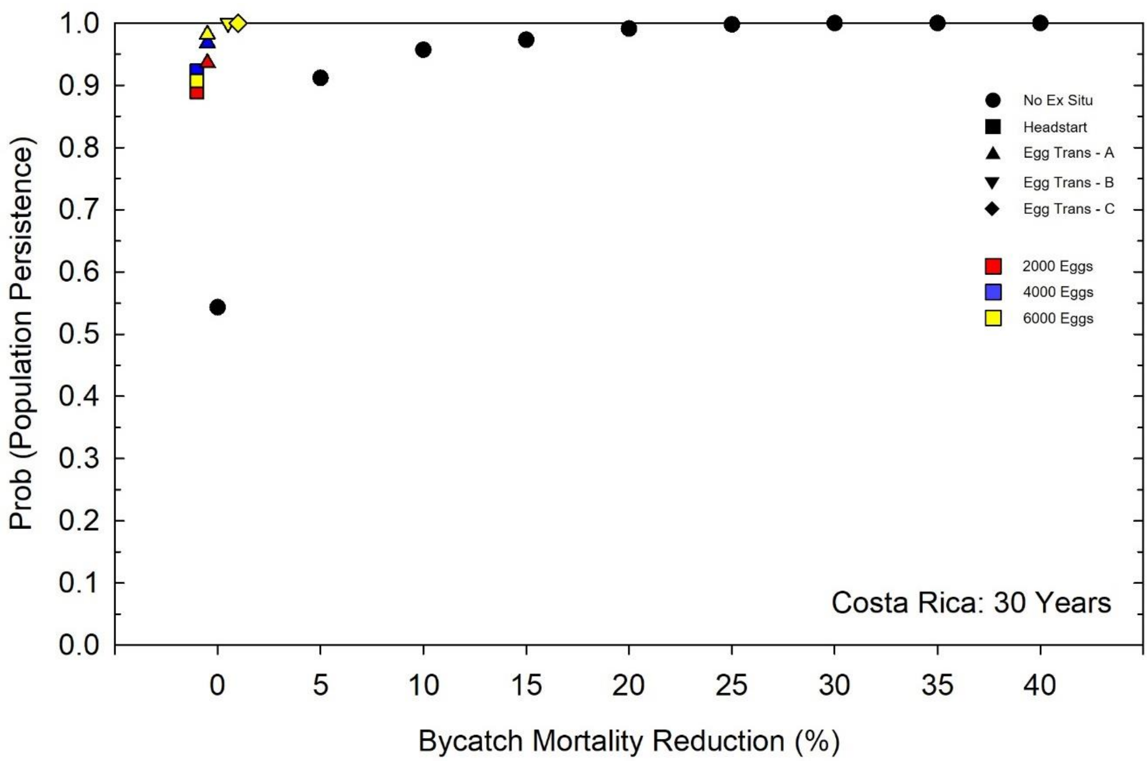


Figure 2-17. Model predictions of probability of persistence of the Costa Rica subpopulation at year 30 under the range of *in situ* and *ex situ* management scenarios. Scenarios featuring only *in situ* management (including increased hatchling emergence through nesting beach protection and reduced subadult and adult mortality through fisheries bycatch mitigation) are denoted by black circles. Scenarios featuring the additional implementation of a given *ex situ* management option are denoted by one of the distinct symbols identified in the figure legend. The level of implementation effort for a given *ex situ* management option (defined by the number of eggs collected each year for management) is denoted by one of the three colors identified in the figure legend. Each management scenario is therefore defined by a specific symbol-color combination. For example, a headstarting (HS) management option that collects 2000 eggs each year for the duration of that program is represented by a red square, while a yellow diamond represents the collection of 6000 eggs annually for the egg translocation type – C (ET-C) management option. Within each category of bycatch mortality mitigation, the symbols representing management scenarios have been jittered horizontally for easier reading. See accompanying text for additional details on model structure and implementation.

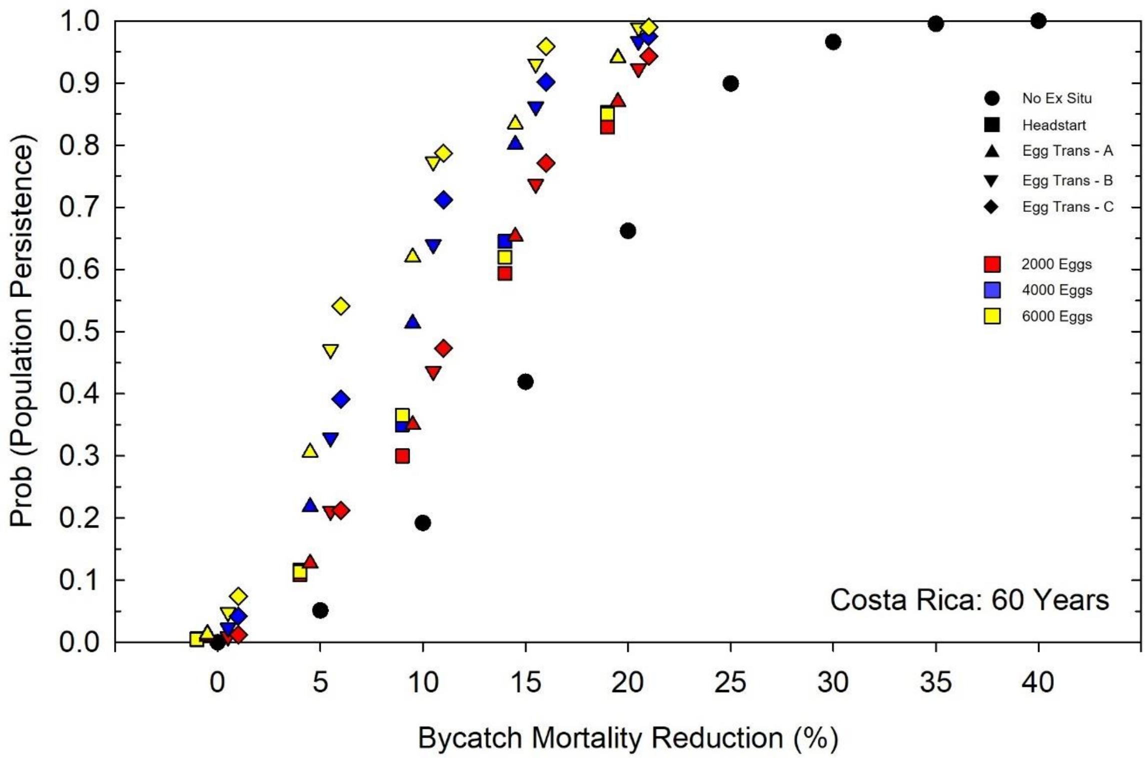


Figure 2-18. Model predictions of probability of persistence of the Costa Rica subpopulation at year 60 under the range of *in situ* and *ex situ* management scenarios. Scenarios featuring only *in situ* management (including increased hatchling emergence through nesting beach protection and reduced subadult and adult mortality through fisheries bycatch mitigation) are denoted by black circles. Scenarios featuring the additional implementation of a given *ex situ* management option are denoted by one of the distinct symbols identified in the figure legend. The level of implementation effort for a given *ex situ* management option (defined by the number of eggs collected each year for management) is denoted by one of the three colors identified in the figure legend. Each management scenario is therefore defined by a specific symbol-color combination. For example, a headstarting (HS) management option that collects 2000 eggs each year for the duration of that program is represented by a red square, while a yellow diamond represents the collection of 6000 eggs annually for the egg translocation type – C (ET-C) management option. Within each category of bycatch mortality mitigation, the symbols representing management scenarios have been jittered horizontally for easier reading. See accompanying text for additional details on model structure and implementation.

Discussion

This report documents the use of a detailed individual-based stochastic demographic model of leatherback turtle population dynamics in the Eastern Pacific ocean basin. This effort is based on a recent analysis (Laúd OPO Network 2020) that focused on the capacity of *in situ* conservation activities, namely reduction of subadult and adult mortality through fisheries bycatch mitigation and improved nesting beach management, to improve long-term viability of leatherback subpopulations nesting on beaches in Mexico and Costa Rica. The present analysis treats these two populations as functionally separate nesting populations, facilitating a comparison of the prospects for local population recovery under different management scenarios. Moreover, it is a significant extension of that original model, with a much deeper analysis of the potential for various types of *ex situ* management – focused on headstarting eggs collected locally or translocating eggs from an external source – to meaningfully contribute to long-term conservation and recovery of these geographically distinct nesting subpopulations.

It is important to acknowledge here that the group of species experts and management authorities that participated in the conservation planning workshops surrounding this PVA did not arrive at a functional definition of what constitutes a meaningful contribution to species recovery for a given management alternative – whether focused on *in situ* or *ex situ* activities. This type of definition is complex, involving both purely biological elements – such as, for example, a threshold increase in population abundance or mean annual growth rate – as well as any number of other factors that could include socio-cultural concerns, economic feasibility, or political realities. Discussions among workshop participants brought forth critical information on the general categories that should be considered when making decisions on future management actions to aid in leatherback turtle conservation. However, these categories do not currently feature more quantitative boundaries that could be used to “classify” management options on their success. Additional work in this area would greatly improve the decision-making process that guides conservation of this species.

Under the assumption of no changes to existing management regimes – in other words, continuing both nesting beach protection as well as some attention to mitigating mortality of older turtles through fisheries bycatch – the present model suggests that this status quo condition will lead to continued rapid rates of decline in nesting females in both Mexico and Costa Rica. As this decline continues at a rate of nearly 15% per year for each subpopulation, the risk of local population extinction (subpopulation extirpation) grows steadily. The smaller Costa Rica subpopulation is particularly vulnerable to disappearing, with the risk of extinction growing to 50% in a little more than 30 years from today. If left unchecked, the threats to leatherback survival will almost certainly lead to local extinction of both subpopulations within the next 50-60 years. The leatherback turtle conservation community is united in recognizing the great need to (1) enhance nesting beach protection efforts, and (2) reduce the mortality of ocean-going individuals as they interact with and ultimately become trapped in fishing gear, both smaller-scale net-based fisheries and industrial-scale pelagic longline operations.

In keeping with the earlier Laúd OPO Network analysis, the present work highlights the significant benefits to be gained through aggressive management of bycatch-related mortality. While adult females in each of the identified subpopulations are assumed to move to separate beaches during the nesting season, there is no detailed treatment in this model of their location and movement patterns between reproductive cycles. Subadult and adult males and females are assumed to inhabit roughly the same areas during this time, so that a given level of spatially-distributed bycatch mitigation impacts age-sex cohorts in the same manner. It is difficult to evaluate this assumption, given difficulties in tracking large numbers of older individuals through time across expansive pelagic habitats. In general, the models described here operate on the assumption that mitigating mortality preferentially among individuals belonging to a given subpopulation would benefit only that subpopulation, particularly in the case of females. The extent to which that assumption is violated among leatherback turtles in the Eastern Pacific is unknown.

The present analysis was motivated by a desire to investigate, in an unbiased manner, the potential for *ex situ* management options to improve opportunities for leatherback recovery. However, because this type of management has not been previously applied systematically to leatherback populations for their conservation, the process of developing quantitative parameters that describe the expected characteristics of this option is characterized by considerable uncertainty. This forces us to make a series of assumptions about the success of different stages of *ex situ* management – survival during transport of translocated eggs; hatching rate of eggs in *ex situ* facilities and the resulting survival of hatchlings to an age suitable for release; and, perhaps most importantly, the survival of released hatchlings relative to their wild-born counterparts. More broadly, there is great uncertainty around the capacity for young turtles translocated from one location to the Eastern Pacific – perhaps even from another ocean basin – to demonstrate proper navigational and other behavioral profiles that would improve their ability to survive and reproduce (e.g., Lohmann et al. 2012).

As a result of recognizing these numerous areas of uncertainty, it is important to acknowledge that the specific results of the models described in this report cannot be taken as absolute predictions of the future status of nesting leatherback subpopulations in Mexico or Costa Rica. Some of the assumptions made in this analysis, while made by biologists recognized for their expertise in leatherback biology and ecology, may by highly optimistic or pessimistic when compared to their true values. These incorrect assumptions will lead to model predictions that would not be consistent with direct observation of turtles in wild environments, or those actually maintained in *ex situ* facilities. We must therefore interpret the results described in this report with considerable caution.

Despite these caveats, the models described here provide important results that should be applied when considering the potential value of *ex situ* management to leatherback turtle recovery in the Eastern Pacific. For example, these models suggest that headstarting efforts using eggs collected from local beaches, with release of individuals back to the ocean environment after management in *ex situ* facilities for about three months, do not provide substantial benefit to long-term leatherback turtle abundance. In order to have any realistic opportunity for successful implementation, headstarting must rely on significant improvements in survival of individuals collected from the wild – both while in the *ex situ* environment and after release – relative to those turtles remaining in the wild. Even when we assume a 50% improvement in post-release survival to one year of age among headstarted individuals relative to wild hatchlings, the long-term additional benefits of this management action are small when applied in concert with modest levels of bycatch mitigation efforts. If survival of subadult and adult turtles is significantly improved through bycatch mitigation, the relative gains from a headstarting program increase accordingly. However, this observed improvement through headstarting critically relies on at least two important assumptions: (1) hatchlings raised for three months under *ex situ* conditions will survive at a rate that is at least close to their wild counterparts of the same age; and (2) released individuals will survive at markedly higher rates than wild turtles, presumably owing to improved predator avoidance and other benefits of growing to (anticipated) larger sizes in captivity. A "white paper" currently in preparation by Williamson et al. (2021) discusses the details around these assumptions, and the means by which improved management can be achieved.

The implications of our uncertainty in these parameters was explored in a simple fashion in this analysis, where a focused sensitivity analysis was conducted to assess the impacts of uncertainty in our estimate of post-release survival of headstarted hatchlings. Under the conditions simulated here, our analysis indicated that the results are indeed quite sensitive to this parameter. If survival of headstarted individuals is instead only marginally improved compared to wild-born turtles, a dedicated headstarting effort is unlikely to provide meaningful benefit if conducted parallel to additional *in situ* management activities. Moreover, if released individuals are not as robust as their wild counterparts, and consequently suffer higher rates of mortality in their new wild environment, it is perhaps not surprising to conclude that a headstarting program would actually be detrimental to the subpopulation to which that management activity is applied. In light of this analysis and associated discussions that were conducted as part of this larger project, it is recommended that any proposal to initiate a headstarting program would be preceded by extensive research and experimental trials to better understand the relative survival of hatchling leatherbacks as they live and grow in the *ex situ* environment, and the drivers that influence that survival, as well as the extent to which they survive and thrive after they are returned to their natural ocean habitat. Generating this important information, however, will require overcoming significant challenges around effectively monitoring movements and survival of large numbers of young turtles after they are released. Genomic methods (e.g., Roden et al. 2017; Komoroske et al. 2017) hold considerable promise for effectively monitoring individuals after release.

The observation that improving survival of young individuals does relatively little to significantly impact long-term nesting female abundance is consistent with previous studies of marine turtle population growth models that clearly demonstrate the key importance of subadult and adult survival for driving population dynamics (e.g., Crouse et al. 1987; Crowder et al. 1994). These insights have been used in other analyses of the limited capacity for headstarting to compensate for high mortality of older age classes of species like marine turtles with long adult lifespans (Heppell et al. 1996). Nevertheless, headstarting has been used in selected marine turtle species, with varying levels of success, as reviewed in Williamson et al. (2021). A well-known example of this practice is the head-start program for green turtles at the Grand Cayman Turtle Farm on Grand Cayman Island. More than 30,000 hatchling and yearling turtles, hatched from eggs laid by resident adults, were released into surrounding waters between 1980 and 2001 (Bell et al. 2005). Once thought to be extirpated from the area, there are now approximately 150 females nesting on Grand Cayman with a large majority of these individuals identified as headstarts or their direct descendants (Barbanti et al. 2019). As the total number of individuals released from the Farm is not currently known, it is impossible to evaluate the success rate for this practice.

In contrast to the type of headstarting effort simulated in this analysis, our models suggest that egg translocation options hold greater promise for contributing more effectively to overall Eastern Pacific leatherback turtle conservation management. This should not be surprising on a simple numerical basis, as the individuals subject to this kind of *ex situ* management are entirely additive to the subpopulation to which they are translocated. This is different from a headstarting program, in which the survival of a sample of turtle eggs from the local beach is targeted to improve survival above what would otherwise be expected if the eggs were allowed to hatch naturally and the hatchlings were to attempt to survive the earliest weeks of life after leaving the nest. A well-known example of applying this technique to marine turtle conservation is the bi-national Kemp's ridley sea turtle (*Lepidochelys kempii*) program in Mexico and Texas. Eggs collected from the Mexican state of Tamaulipas were ultimately transferred to southern Texas and released there after additional incubation (Caillouet et al 2015). The program has been credited with helping to expand the nesting area for the species in the Gulf of Mexico (Shaver et al. 2016), and to improving the status of the species overall (Caillouet et al 2015; Shaver and Caillouet 2015). However, the rate of headstarted individuals surviving to breeding age and returning to their release site to nest has been quite low, less than 1:400. This and other challenges have led to external reviews of the management program (e.g., Wibbles et al. 1989; Eckert et al. 1994) and criticism of the program for its apparent lack of success and significant financial cost (e.g., Woody 1991; Taubes 1992). The conversation around this controversial program continues to this day.

Despite the apparent benefits that egg translocation may be able to offer, there are significant concerns around the feasibility of this option. Firstly, there is the issue of finding a suitable source population that could tolerate the removal of a substantial number of eggs without compromising that population's demographic stability. A simulation analysis very similar to that described here could be developed to assist in identifying a population that could serve this function. Secondly, there is the concern about the capacity of translocated individuals to successfully adapt to their new surroundings. For example, translocation carries the risk of introducing novel pathogens to naïve populations, although the breadth of knowledge around infectious disease processes in marine turtle populations appears to be quite limited (Mashkour et al. 2020). Additionally, translocation could lead to disruption of local population genetic structure through admixture of genes from different populations. Finally, turtles may be genetically "hard-wired" to use various navigational cues to successfully thrive in the ocean basin from which they and their ancestors are derived (Lohmann et al. 2012). Translocating individuals from one basin to another, or perhaps even among different locations within the same basin, may disrupt their ability to display normal ecological behaviors necessary for feeding, breeding, and nesting. There is simply no agreement yet on whether this is a significant problem that would restrict the opportunities for successful translocation of leatherback eggs to the Eastern Pacific. Once again, dedicated study of this issue through appropriate experimentation should be required before translocation is adopted as an *ex situ* management option of choice for leatherback conservation.

It may be interesting to note that many of the *ex situ* management strategies evaluated here could be important tools for reducing the likelihood of local extirpation of the Mexico and the Costa Rica subpopulations – in essence, using *ex situ* management to "buy time" for saving the subpopulations from extinction if *in situ* efforts are slow to develop or are insufficient. This concept is explicitly identified as an important role that *ex situ* populations and their active management can play in the larger species conservation effort (IUCN/SSC 2014). The comparative summary plots of persistence probability (Figures 14, 17 and 18) show the potential for considerable gains in maintaining subpopulation presence, particularly if fisheries bycatch mortality mitigation is low and if egg translocation can be successfully implemented for the reasons provided previously. It is important to recognize that this improvement in subpopulation persistence is the result of *ex situ* management contributing a substantial number of young turtles to the total subpopulation abundance. While implementing this management option may reduce the chance of the subpopulation disappearing entirely, it does not naturally lead to a similarly substantial increase in nesting females over time (e.g., compare the output data for 10% bycatch mortality mitigation in Figures 16 and 18). This is the inevitable consequence of unsustainably high mortality of subadults and adults in the face of insufficient bycatch mitigation; increasing the number of younger turtles through translocation could, if bycatch mortality remains high, effectively serve to add more turtle biomass to interact with the fishing gear distributed throughout the Eastern Pacific – often with fatal consequences. Nevertheless, a combined management strategy featuring both *in situ* and *ex situ* components could work synergistically to save a subpopulation from extinction in the short-term and, through continued efforts directed at reducing *in situ* threats to individual survival, improve long-term prospects for recovery.

Finally, it is acknowledged here that the decisions regarding *ex situ* management are not to be based solely on the results of this quantitative analysis. As with any high-stakes decision in species conservation, numerous factors should be considered together before a particular decision is made. As recognized by many of the participants in this project, another important factor besides capacity for increasing subpopulation abundance is the overall economic cost of any given management action. Careful consideration must be given to the estimated financial cost of the *ex situ* management options considered here, so that a responsible measure of cost-effectiveness – the extent of subpopulation abundance benefit per unit financial expenditure – can be calculated. In an identical manner, the financial costs associated with a given level of *in situ* fisheries bycatch mitigation should also be estimated so that a meaningful comparison across the full suite of population management options can be undertaken. Other important factors identified by participants included: minimize demographic impacts to source populations, avoid compromising efforts to secure funding for *in situ* management activities, and improve opportunities for local community engagement in recovery efforts. Using this broad approach, those engaged in leatherback conservation in the Eastern Pacific can create a unified vision for what is required to save these subpopulations from extinction.

Acknowledgements

Many thanks to the PVA Workshop participants for their creative energy and dedicated collaboration during the technical process of model development and testing. Additional thanks goes to the subset of participants who provided valuable comments on a draft version of this report.

Special thanks to Bibi Santidrián Tomillo (The Leatherback Trust) and Meritxell Genovart (CEAB – CSIC) for their invaluable assistance with providing details of the Laúd OPO Network demographic model. In addition, many thanks to Bob Lacy (Species Conservation Toolkit Initiative) and Kathy Traylor-Holzer (IUCN SSC Conservation Planning Specialist group) for their helpful comments and suggestions throughout the model development process.

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Appendix A.

PVA Workshop Participants

Name	Institution
Juan Manuel Rodriguez Baron	JUSTSEA Foundation
Jamie Copsey	Conservation Planning Specialist Group (IUCN SSC)
Nestor Davalos	Centro Interdisciplinario de Ciencias Marinas, Mexico
Martha Harfush	Mexican Turtle Center
Daisy Herrera	FIAES, El Salvador
Philip Miller	Conservation Planning Specialist Group (IUCN SSC)
Nicki Mitchell	University of Western Australia
Walter Mustin	Cayman Turtle Center
Anna Ortega	University of Western Australia
Richard Reina	Monash University
Laura Sarti	CONANP, Mexico
Donna Shaver	U.S. National Park Service
George Shillinger	Upwell
Callie Veelenturf	The Leatherback Project
Bryan Wallace	Eco-librium, Inc.
Sean Williamson	Monash University / Upwell
Jeanette Wyneken	Florida Atlantic University

Appendix B.

Eastern Pacific Leatherback Turtle *Ex Situ* Feasibility Analysis: Identifying Threshold Headstarting Management Parameters for Population Viability Modeling

Introduction

A core requirement for successful implementation of headstarting as a proposed options for *ex situ* management of the Eastern Pacific leatherback turtle (*Dermochelys coriacaea*) is that survival (to a given point in time) of eggs collected for the program must be at least equivalent to that of wild eggs that develop on the beaches in Mexico and Costa Rica currently used by nesting females. More specifically, we may state that the number of Age-1 individuals (12 months old from the day the eggs are laid) produced through a successful headstarting effort must be at least as many as – and ideally appreciably greater than – the number produced from a nesting female over a given nesting season.

Derivation of Management Parameters

We can calculate the expected mean number of yearlings turtles produced on (for example) nesting beaches in Mexico, based on the information provided in the PVA paper recently published in 2020 by the Laúd OPO Network:

- Number of eggs laid per nesting female: 390
- Survival of eggs to hatchlings successfully reaching the water: 0.464
- Number of hatchlings successfully reaching the water: 181
- Survival to 1 year of age: 0.063 (mean monthly survival: 0.794)
- Number of yearlings (Age-1) produced per nesting female: 181 * 0.063 = 11.4

Under a conservation scenario featuring enhanced beach protection and improved nest conditions that result in increased hatchling production, the total survival of hatchlings that successfully reach the water is increased by approximately 50%, as described by the "increased emergence" scenario of Laúd OPO (2020). Therefore, under this improved management scenario, the number of yearling (Age-1) turtles produced per nesting female increases to 17.1.

If headstarting is to be considered as a potentially viable management component, the number of yearlings produced must be, at a bare minimum, at least as many as the numbers calculated above. We assume here that a headstart program features collection of eggs on candidate Mexico nesting beaches, with subsequent incubation of those eggs at a nearby incubation facility. We can consider the number of yearlings produced through headstarting $N_{\mathrm{Yrl,HS}}$ according to the following formulation:

$$N_{\mathrm{Yrl,HS}} = m_{\mathrm{F}} * \mathrm{HS} * S_{\mathrm{R}} * S_{\mathrm{PR}}$$

where

m_{F} = maternity of nesting females (mean number of eggs laid by each nesting female)
HS = hatching success (mean proportion of eggs that hatch)
S_R = mean hatchling survival in the incubation facility until time of release (taken to be 3 months)
S_{PR} = mean post-release survival of individuals to 1 year of age, i.e., 9 months after release

For the calculations presented here, we assume m_{F} = 390, as above. We will also assume that, following on from Williamson et al. (2021), we could reasonably expect a hatching success rate of 75%

when headstarting efforts are successfully established, although lower success rates (e.g., 50%) would be expected at the outset of the program. Additionally, we will assume that young turtles produced through headstarting will be larger than their wild-raised counterparts at a given age, and will therefore be able to better escape predation in the first months after release. This improvement in post-release survival will be referred to as ΔS_{PR}. If ΔS_{PR} is assumed to be 1.5, this 50% improvement in total 9-month survival to Age-1 is equivalent to a monthly improvement in survival of approximately 4.6%. Finally, we will assume that our ambitious goal for a proposed headstarting program is a minimum 20% increase in the number of yearlings produced compared to the number produced by a wild nesting female. (Note that this increase is arbitrary and not derived through consultation with the full body of experts involved with this process.) With this information in hand, we can explore the values of headstart hatchling survival required to generate this desired level of production.

The results of this analysis are shown in Figure A-1. If improved hatching success from managed nests were not to be implemented (equivalent to the "baseline emergence" scenario), and if we assume no improved survival of headstarted individuals after their release (ΔS_{PR} = 1.0), survival of hatchlings in the incubation facility to three months of age would need to be approximately 37% in order to reach the expected increased production of yearlings through headstarting. On the other hand, if post-release survival were to increase by a total of 50% over the nine months until the turtles reach one year of age (ΔS_{PR} = 1.5), hatchling survival in the facility must be approximately 25% for the same level of expected yearling production. If the production of yearlings from wild nests were to be increased through improved beach protection ("increased emergence"), survival rates in the headstart program would need to correspondingly increase for the *ex situ* program to be considered successful.

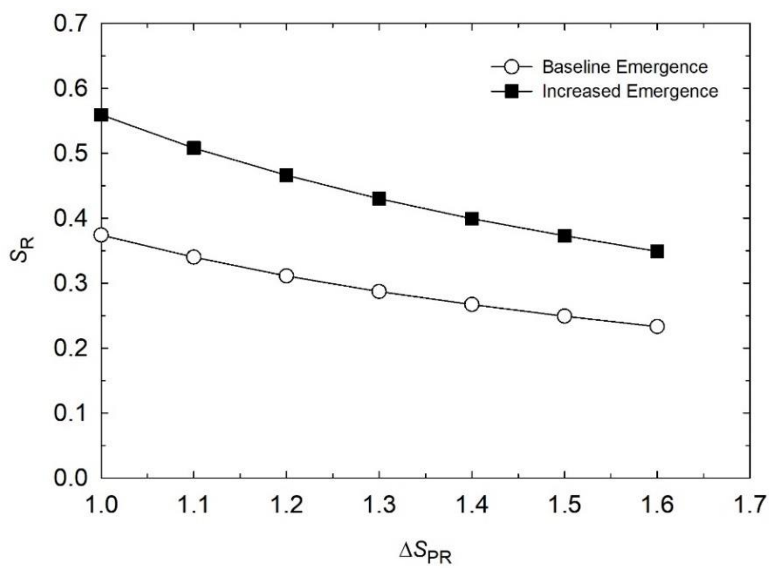

Figure A-1. Early stage-specific hatchling survival rates required to realize a 20% increase in yearling (Age-1) production through proposed headstarting efforts. S_R, survival of incubated hatchlings to time of release at three months of age. ΔS_{PR}, proportional increase in post-release survival to 12 months of age, relative to estimated survival of wild individuals. "Increased emergence" scenario taken from Laúd OPO (2020), with a 50% increase in emergence success on managed beaches through increased protection. All calculations assume 390 eggs per nesting female and a 75% hatching success of incubated eggs.

Figure A-2 shows comparative trajectories of the mean number of wild and headstarted individuals expected to survive from egg to Age-1, assuming the "baseline emergence" beach protection scenario and the general assumptions outlined above which include a 50% increase in total post-release survival of headstarted hatchlings to Age-1. In addition, we assume a survival rate of hatchlings to three months of age (S_R) of 40%. Under these conditions, the number of Age-1 individuals produced from a single nesting female and from the same number of eggs managed through headstarting is expected to be 11.4 and 22.0, respectively. This 93% increase in yearling production is certainly higher than the 20%

goal, and reflects the improved consequences of S_R = 40% survival which is greater than that required to achieve the 20% improved production goal (see Figure A-1). On the other hand, if hatching success in *ex situ* conditions is low (50%), survival to release remains at 40% and the survival of released individuals is no better than their wild counterparts, the expected number of Age-1 turtles is 14% less than that produced in the wild (9.8 vs. 11.4) and less than half of what would be expected under more favorable headstarting conditions (9.8 vs. 22.0). These calculations demonstrate the sensitivity of these models to the underlying assumptions regarding success of *ex situ* management.

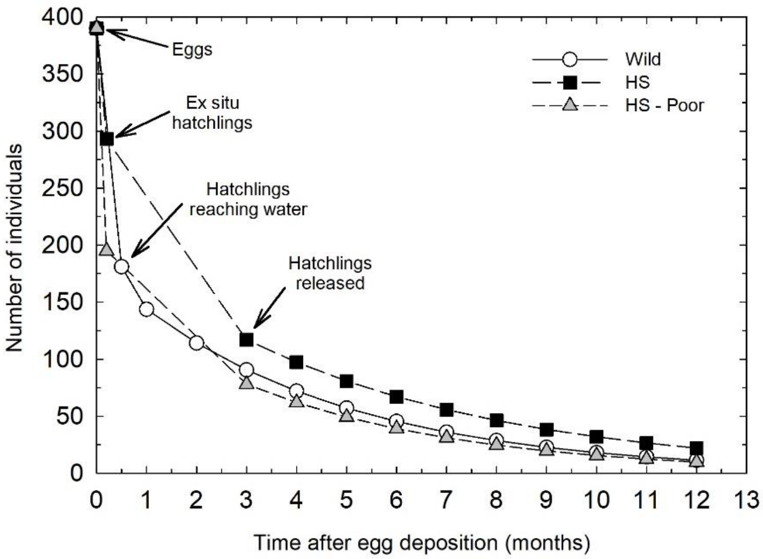

Figure A-2. Expected number of individuals remaining from an initial quantity of 390 eggs (assumed production of a single nesting female) and with standard or poor estimates of survival during headstarting (HS). Survival rates used for wild eggs are taken from Laúd OPO (2020). Standard HS scenario assumes 75% hatching success, 40% survival of hatchlings to release at three months, and an overall 50% proportional increase in post-release hatchling survival compared to that expected for wild hatchlings. The Poor HS scenario assumes 50% hatching success, and post-release survival equal to that first-year survival of wild turtles. Calculations assume no increased hatchling production in natural nests through improved beach protection.

Conclusions

From these analyses, we can derive the following demographic input parameters for the *ex situ* management component of our population viability analysis using the *Vortex* simulation software:

- Overall management goal of at least a 20% increase in the number of yearling (Age-1) turtles produced through headstarting relative to the yearling production from eggs allowed to develop naturally.
- Final hatching success rate in the incubation facility of 75%. However, it is unlikely that this level of success will be achieved from the outset of the headstarting program. We will account for this learning process by initially assuming a 50% hatching rate, which will increase steadily over five years to the final 75% success rate.
- Final hatchling survival rate in the incubation facility of 40% to the time of release at three months of age. In a manner similar to that for the hatching success discussed above, we will initially assume a 25% hatchling survival rate to three months, which will also increase steadily over five years to the final 40% success rate. The dynamic structure of these two parameters seems realistic and prudent in light of the recognized difficulties in raising leatherback turtles in an *ex situ* environment.
- Post-release survival of headstarted hatchlings to Age-1 (12 months old) is 50% higher than the rate assumed over the same time period for hatchlings emerging from natural nests.

It is important to remember that the parameters defined above govern the mean survival of individual turtles only through their first year. In order for headstarted individuals to fully contribute to the long-term recovery of population viability, they must survive to reproductive age – 12 years for females, 16 years for males. This process will be controlled by the mean survival rates for juvenile and subadult turtles taken from the Laúd OPO (2020) analysis.

The information discussed above will be used to define the range of headstarting management scenarios to be evaluated in this project. This and other forms of *ex situ* management (e.g., egg translocation) will be implemented either in the absence of presence of *in situ* management activities as defined in the Laúd OPO (2020) analysis – namely, increased hatchling production through improved beach protection (as described above) and across a range of fisheries bycatch mitigation intensities, simulated through proportional reduction in annual subadult and adult mortality rates. Headstarting management scenarios will be largely distinguished by the extent of management effort, i.e., the number of eggs collected from local beaches and transferred to the nearby incubation facility. The duration of headstarting efforts may also be examined in addition to the extent of egg collection in any one year.

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Appendix C.

Numerical Results of Management Scenarios

The following pages list the key output metrics for each of the 225 management scenarios discussed in this report. Each page is organized at the highest level by the extent of fisheries bycatch mortality mitigation, defined as the proportional reduction in subadult and adult mortality relative to the status quo scenario. For each value of bycatch mitigation, there are four blocks of scenarios defined by the type of *ex situ* management option being employed. Within each *ex situ* management option, the scenarios are organized according to (1) the number of eggs subject to that management option (2000, 4000, or 6000 eggs), and (2) the country to which the management option is being applied (Mexico, Costa Rica).

Note that each page begins with the scenario in which no *ex situ* management option is being employed, i.e., *in situ* management only.
In the first set of model results, the assumption is that no additional bycatch mortality mitigation is being employed, meaning that *ex situ* management is the only additional option being applied to the subpopulations of interest.

Output metrics are reported at 30 and 60 years from the beginning of the simulation, for each of the component subpopulations as well as the aggregate metapopulation. Metrics include:

Prob(Persistence)	Probability that the subpopulation receiving *ex situ* management will remain in existence
Nesting female abundance	Mean number of adult females tallied as nesting in that year (approximately 30% of the total number of adult females), among all model iterations in which the subpopulation was in existence
Adult female abundance	Mean number of all adult females tallied in that year (approximately 3.3x the number of nesting females), among all model iterations in which the subpopulation was in existence

Output metrics for that subpopulation which was not the subject of direct *ex situ* management in a given scenario are de-emphasized in gray font, as the results for those subpopulations are not expected to be meaningfully impacted by the management option. Variability in output is, therefore, primarily the result of random fluctuations in demographic rates from one year to the next.

C

Numerical Results of Management Scenarios

0% Fisheries Bycatch Mortality Mitigation

	Prob [Persistence]					
	30yrs - MX	60yrs - MX	30yrs - CR	60yrs - CR	30yrs - Meta	60yrs - Meta
No Ex Situ	0.935	0.020	0.543	0.000	0.953	0.020
Headstart - 2000 - MX	0.978	0.039	0.532	0.002	0.983	0.042
Headstart - 4000 - MX	0.985	0.051	0.608	0.006	0.989	0.062
Headstart - 6000 - MX	0.992	0.047	0.598	0.002	0.993	0.051
Headstart - 2000 - CR	0.948	0.023	0.889	0.004	0.980	0.029
Headstart - 4000 - CR	0.958	0.017	0.923	0.006	0.990	0.023
Headstart - 6000 - CR	0.954	0.024	0.907	0.005	0.985	0.034
Egg Trans A - 2000 - MX	0.997	0.034	0.582	0.001	0.999	0.037
Egg Trans A - 4000 - MX	0.999	0.074	0.600	0.001	0.999	0.082
Egg Trans A - 6000 - MX	1.000	0.095	0.626	0.004	1.000	0.107
Egg Trans A - 2000 - CR	0.935	0.021	0.936	0.009	0.988	0.029
Egg Trans A - 4000 - CR	0.939	0.023	0.968	0.014	0.998	0.038
Egg Trans A - 6000 - CR	0.953	0.032	0.982	0.013	0.999	0.044
Egg Trans B - 2000 - MX	0.999	0.046	0.582	0.002	0.999	0.052
Egg Trans B - 4000 - MX	1.000	0.109	0.636	0.006	1.000	0.120
Egg Trans B - 6000 - MX	1.000	0.178	0.676	0.005	1.000	0.208
Egg Trans B - 2000 - CR	0.951	0.024	1.000	0.009	1.000	0.036
Egg Trans B - 4000 - CR	0.957	0.045	1.000	0.023	1.000	0.071
Egg Trans B - 6000 - CR	0.974	0.046	1.000	0.048	1.000	0.097
Egg Trans C - 2000 - MX	1.000	0.068	0.653	0.002	1.000	0.084
Egg Trans C - 4000 - MX	1.000	0.138	0.586	0.009	1.000	0.151
Egg Trans C - 6000 - MX	1.000	0.250	0.751	0.007	1.000	0.261
Egg Trans C - 2000 - CR	0.964	0.035	1.000	0.012	1.000	0.048
Egg Trans C - 4000 - CR	0.972	0.042	1.000	0.042	1.000	0.086
Egg Trans C - 6000 - CR	0.973	0.071	1.000	0.074	1.000	0.130

	Nesting Female Abundance					
	30yrs - MX	60yrs - MX	30yrs - CR	60yrs - CR	30yrs - Meta	60yrs - Meta
No Ex Situ	2.01	0.00	0.00	0.00	2.01	0.00
Headstart - 2000 - MX	2.53	0.10	0.47	0.00	3.00	0.10
Headstart - 4000 - MX	3.30	0.10	0.45	0.00	3.75	0.10
Headstart - 6000 - MX	3.74	0.21	0.51	0.00	4.25	0.21
Headstart - 2000 - CR	2.07	0.09	0.66	0.00	2.73	0.09
Headstart - 4000 - CR	2.06	0.00	0.82	0.17	2.88	0.17
Headstart - 6000 - CR	2.21	0.04	0.83	0.00	3.04	0.04
Egg Trans A - 2000 - MX	2.63	0.12	0.43	0.00	3.06	0.12
Egg Trans A - 4000 - MX	3.73	0.12	0.43	0.00	4.16	0.12
Egg Trans A - 6000 - MX	4.81	0.23	0.57	0.25	5.38	0.48
Egg Trans A - 2000 - CR	2.03	0.00	0.68	0.11	2.71	0.11
Egg Trans A - 4000 - CR	2.30	0.13	1.10	0.07	3.40	0.20
Egg Trans A - 6000 - CR	2.42	0.19	1.59	0.62	4.01	0.81
Egg Trans B - 2000 - MX	2.99	0.13	0.39	0.00	3.38	0.13
Egg Trans B - 4000 - MX	4.98	0.19	0.55	0.17	5.53	0.36
Egg Trans B - 6000 - MX	6.75	0.25	0.53	0.00	7.28	0.25
Egg Trans B - 2000 - CR	2.14	0.08	1.16	0.00	3.30	0.08
Egg Trans B - 4000 - CR	2.31	0.07	2.38	0.09	4.69	0.16
Egg Trans B - 6000 - CR	2.66	0.13	3.68	0.04	6.34	0.17
Egg Trans C - 2000 - MX	3.52	0.34	0.44	0.00	3.96	0.34
Egg Trans C - 4000 - MX	6.01	0.37	0.49	0.00	6.50	0.37
Egg Trans C - 6000 - MX	8.05	0.31	0.54	0.14	8.59	0.45
Egg Trans C - 2000 - CR	2.47	0.20	1.44	0.33	3.91	0.53
Egg Trans C - 4000 - CR	2.73	0.14	2.84	0.12	5.57	0.26
Egg Trans C - 6000 - CR	2.63	0.18	4.77	0.09	7.40	0.27

	Adult Female Abundance					
	30yrs - MX	60yrs - MX	30yrs - CR	60yrs - CR	30yrs - Meta	60yrs - Meta
No Ex Situ	6.71	0.00	1.33	0.00	8.04	0.00
Headstart - 2000 - MX	8.45	0.34	1.56	0.00	10.01	0.34
Headstart - 4000 - MX	11.00	0.33	1.50	0.00	12.50	0.33
Headstart - 6000 - MX	12.48	0.71	1.71	0.00	14.19	0.71
Headstart - 2000 - CR	6.90	0.29	2.20	0.00	9.10	0.29
Headstart - 4000 - CR	6.87	0.00	2.72	0.56	9.59	0.56
Headstart - 6000 - CR	7.36	0.14	2.76	0.00	10.12	0.14
Egg Trans A - 2000 - MX	8.75	0.39	1.43	0.00	10.18	0.39
Egg Trans A - 4000 - MX	12.44	0.41	1.42	0.00	13.86	0.41
Egg Trans A - 6000 - MX	16.02	0.77	1.90	0.83	17.92	1.60
Egg Trans A - 2000 - CR	6.76	0.00	2.28	0.37	9.04	0.37
Egg Trans A - 4000 - CR	7.67	0.43	3.67	0.24	11.34	0.67
Egg Trans A - 6000 - CR	8.05	0.63	5.29	2.05	13.34	2.68
Egg Trans B - 2000 - MX	9.95	0.43	1.31	0.00	11.26	0.43
Egg Trans B - 4000 - MX	16.60	0.64	1.82	0.56	18.42	1.20
Egg Trans B - 6000 - MX	22.51	0.84	1.76	0.00	24.27	0.84
Egg Trans B - 2000 - CR	7.13	0.28	3.85	0.00	10.98	0.28
Egg Trans B - 4000 - CR	7.72	0.22	7.93	0.29	15.65	0.51
Egg Trans B - 6000 - CR	8.88	0.43	12.27	0.14	21.15	0.57
Egg Trans C - 2000 - MX	11.72	1.13	1.46	0.00	13.18	1.13
Egg Trans C - 4000 - MX	20.04	1.23	1.63	0.00	21.67	1.23
Egg Trans C - 6000 - MX	26.84	1.03	1.80	0.48	28.64	1.51
Egg Trans C - 2000 - CR	8.25	0.67	4.79	1.11	13.04	1.78
Egg Trans C - 4000 - CR	9.09	0.48	9.46	0.40	18.55	0.88
Egg Trans C - 6000 - CR	8.78	0.61	15.91	0.32	24.69	0.93

Appendix C. (Continued)

Numerical Results of Management Scenarios

5% Fisheries Bycatch Mortality Mitigation

	Prob [Persistence]						Nesting Female Abundance						Adult Female Abundance					
	30yrs - MX	60yrs - MX	30yrs - CR	60yrs - CR	30yrs - Meta	60yrs - Meta	30yrs - MX	60yrs - MX	30yrs - CR	60yrs - CR	30yrs - Meta	60yrs - Meta	30yrs - MX	60yrs - MX	30yrs - CR	60yrs - CR	30yrs - Meta	60yrs - Meta
No Ex Situ	0.996	0.333	0.912	0.051	0.996	0.350	6.83	0.73	0.89	0.16	7.72	0.89	22.78	2.44	2.98	0.52	25.76	2.96
Headstart - 2000 - MX	1.000	0.406	0.917	0.062	1.000	0.426	7.79	0.81	0.98	0.19	8.77	1.00	25.96	2.71	3.28	0.65	29.24	3.36
Headstart - 4000 - MX	1.000	0.413	0.917	0.068	1.000	0.433	8.05	0.77	0.91	0.22	8.96	0.99	26.83	2.56	3.04	0.74	29.87	3.30
Headstart - 6000 - MX	1.000	0.446	0.916	0.072	1.000	0.477	7.77	0.89	1.01	0.21	8.78	1.10	25.90	2.96	3.37	0.69	29.27	3.65
Headstart - 2000 - CR	0.995	0.364	0.979	0.109	0.999	0.388	7.13	0.88	1.40	0.18	8.53	1.06	23.77	2.95	4.67	0.61	28.44	3.56
Headstart - 4000 - CR	0.997	0.388	0.986	0.116	0.999	0.416	6.81	0.72	1.59	0.22	8.40	0.94	22.69	2.41	5.30	0.72	27.99	3.13
Headstart - 6000 - CR	0.997	0.377	0.988	0.114	1.000	0.415	6.68	0.66	1.59	0.24	8.27	0.90	22.26	2.19	5.31	0.79	27.57	2.98
Egg Trans A - 2000 - MX	1.000	0.481	0.915	0.066	1.000	0.505	8.83	0.95	0.88	0.14	9.71	1.09	29.44	3.17	2.93	0.45	32.37	3.62
Egg Trans A - 4000 - MX	1.000	0.609	0.920	0.109	1.000	0.631	11.56	1.51	0.93	0.28	12.49	1.79	38.52	5.05	3.11	0.92	41.63	5.97
Egg Trans A - 6000 - MX	1.000	0.725	0.961	0.129	1.000	0.745	14.08	1.66	0.99	0.19	15.07	1.85	46.93	5.52	3.29	0.65	50.22	6.17
Egg Trans A - 2000 - CR	0.997	0.401	0.997	0.127	1.000	0.443	7.05	0.76	1.91	0.24	8.96	1.00	23.48	2.54	6.35	0.79	29.83	3.33
Egg Trans A - 4000 - CR	1.000	0.424	0.999	0.218	1.000	0.483	6.77	0.74	3.06	0.26	9.83	1.00	22.58	2.46	10.21	0.86	32.79	3.32
Egg Trans A - 6000 - CR	0.998	0.458	1.000	0.306	1.000	0.549	7.05	0.69	4.02	0.38	11.07	1.07	23.51	2.31	13.93	1.25	37.44	3.56
Egg Trans B - 2000 - MX	1.000	0.512	0.921	0.081	1.000	0.533	9.33	0.97	1.01	0.16	10.34	1.13	31.09	3.25	3.73	0.54	34.82	3.79
Egg Trans B - 4000 - MX	1.000	0.654	0.949	0.105	1.000	0.674	10.73	1.37	0.76	0.10	11.49	1.47	39.13	4.56	3.23	0.32	42.36	4.88
Egg Trans B - 6000 - MX	1.000	0.767	0.955	0.141	1.000	0.785	13.98	1.63	1.05	0.15	15.03	1.78	46.60	5.43	3.50	0.50	50.10	5.93
Egg Trans B - 2000 - CR	0.997	0.437	1.000	0.211	1.000	0.500	7.23	0.82	2.50	0.17	9.73	0.99	24.15	2.72	8.33	0.55	32.48	3.27
Egg Trans B - 4000 - CR	0.999	0.530	1.000	0.329	1.000	0.607	7.88	0.93	4.64	0.34	12.52	1.27	26.27	3.10	15.46	1.12	41.73	4.22
Egg Trans B - 6000 - CR	1.000	0.579	1.000	0.471	1.000	0.680	7.68	0.80	6.35	0.32	14.03	1.12	25.59	2.68	21.17	1.08	46.76	3.76
Egg Trans C - 2000 - MX	1.000	0.538	0.939	0.087	1.000	0.559	9.65	0.97	0.96	0.15	10.61	1.12	32.16	3.25	3.20	0.50	35.36	3.75
Egg Trans C - 4000 - MX	1.000	0.690	0.925	0.126	1.000	0.704	12.17	1.39	0.97	0.09	13.14	1.48	40.56	4.64	3.23	0.29	43.79	4.93
Egg Trans C - 6000 - MX	0.000	0.975	0.984	0.308	1.000	0.979	18.12	3.83	1.20	0.23	19.32	4.06	60.41	12.76	4.01	0.78	64.42	13.54
Egg Trans C - 2000 - CR	0.995	0.426	1.000	0.212	1.000	0.485	7.31	0.77	2.93	0.18	10.24	0.95	24.35	2.55	9.77	0.61	34.12	3.16
Egg Trans C - 4000 - CR	0.998	0.532	1.000	0.391	1.000	0.624	7.26	0.74	5.23	0.33	12.49	1.07	24.21	2.47	17.44	1.11	41.65	3.58
Egg Trans C - 6000 - CR	0.999	0.595	1.000	0.541	1.000	0.713	8.16	0.92	7.59	0.41	15.75	1.33	27.19	3.08	25.31	1.36	52.50	4.44

Appendix C. (Continued)

Numerical Results of Management Scenarios

10% Fisheries Bycatch Mortality Mitigation

	Prob [Persistence]						Nesting Female Abundance						Adult Female Abundance					
	30yrs - MX	60yrs - MX	30yrs - CR	60yrs - CR	30yrs - Meta	60yrs - Meta	30yrs - MX	60yrs - MX	30yrs - CR	60yrs - CR	30yrs - Meta	60yrs - Meta	30yrs - MX	60yrs - MX	30yrs - CR	60yrs - CR	30yrs - Meta	60yrs - Meta
No Ex Situ	1.000	0.611	0.957	0.192	1.000	0.627	10.30	1.91	1.31	0.24	11.61	2.15	34.35	6.36	4.35	0.82	38.70	7.17
Headstart - 2000 - MX	1.000	0.630	0.968	0.172	1.000	0.652	10.46	1.85	1.24	0.23	11.70	2.08	34.85	6.17	4.13	0.76	38.98	6.93
Headstart - 4000 - MX	1.000	0.676	0.960	0.192	1.000	0.696	11.07	2.14	1.30	0.28	12.37	2.42	36.91	7.13	4.35	0.94	41.26	8.06
Headstart - 6000 - MX	1.000	0.741	0.966	0.209	1.000	0.764	11.22	1.95	1.32	0.29	12.54	2.24	37.39	6.50	4.39	0.97	41.78	7.48
Headstart - 2000 - CR	0.998	0.660	0.992	0.300	0.999	0.695	10.22	1.97	2.12	0.36	12.34	2.33	34.07	6.56	7.07	1.21	41.14	7.77
Headstart - 4000 - CR	1.000	0.647	0.995	0.350	1.000	0.686	10.07	1.98	2.41	0.35	12.48	2.33	33.56	6.62	8.02	1.15	41.58	7.77
Headstart - 6000 - CR	1.000	0.659	0.998	0.365	1.000	0.707	10.95	2.21	2.45	0.36	13.40	2.57	36.48	7.35	8.18	1.21	44.66	8.57
Egg Trans A - 2000 - MX	1.000	0.748	0.962	0.225	1.000	0.766	13.02	2.77	1.28	0.27	14.30	3.03	43.39	9.22	4.28	0.89	47.67	10.11
Egg Trans A - 4000 - MX	1.000	0.843	0.977	0.293	1.000	0.857	16.41	3.63	1.35	0.27	17.76	3.90	54.69	12.09	4.50	0.91	59.19	13.00
Egg Trans A - 6000 - MX	1.000	0.890	0.963	0.320	1.000	0.905	18.54	4.73	1.43	0.33	19.97	5.06	61.79	15.78	4.78	1.08	66.57	16.86
Egg Trans A - 2000 - CR	1.000	0.656	1.000	0.350	1.000	0.696	9.82	1.84	2.61	0.36	12.43	2.20	32.72	6.12	8.69	1.21	41.41	7.33
Egg Trans A - 4000 - CR	1.000	0.704	1.000	0.513	1.000	0.760	10.57	2.11	4.27	0.49	14.84	2.59	35.25	7.03	14.23	1.62	49.48	8.65
Egg Trans A - 6000 - CR	1.000	0.750	1.000	0.620	1.000	0.812	11.26	2.48	5.93	0.71	17.19	3.19	37.52	8.26	19.75	2.37	57.27	10.63
Egg Trans B - 2000 - MX	1.000	0.772	0.963	0.224	1.000	0.787	12.99	2.46	1.29	0.25	14.28	2.71	43.29	8.20	4.29	0.82	47.58	9.02
Egg Trans B - 4000 - MX	1.000	0.878	0.971	0.300	1.000	0.892	16.23	3.44	1.38	0.28	17.61	3.72	54.08	11.45	4.60	0.94	58.68	12.39
Egg Trans B - 6000 - MX	1.000	0.923	0.982	0.349	1.000	0.931	20.10	4.82	1.41	0.27	21.51	5.09	67.01	16.07	4.69	0.90	71.70	16.97
Egg Trans B - 2000 - CR	0.999	0.675	1.000	0.436	1.000	0.723	10.17	2.16	3.56	0.48	13.73	2.64	33.90	7.19	11.88	1.61	45.78	8.80
Egg Trans B - 4000 - CR	1.000	0.781	1.000	0.640	1.000	0.843	10.62	1.82	6.04	0.61	16.66	2.43	35.40	6.07	20.12	2.03	55.52	8.10
Egg Trans B - 6000 - CR	1.000	0.811	1.000	0.773	1.000	0.899	11.13	2.29	8.47	0.92	19.60	3.21	37.09	7.64	28.22	3.05	65.31	10.70
Egg Trans C - 2000 - MX	1.000	0.785	0.969	0.253	1.000	0.808	13.86	2.95	1.41	0.16	15.27	3.11	46.21	9.83	4.72	0.54	50.93	10.37
Egg Trans C - 4000 - MX	1.000	0.904	0.981	0.305	1.000	0.912	17.46	3.78	1.41	0.31	18.87	4.09	58.20	12.59	4.69	1.05	62.89	13.64
Egg Trans C - 6000 - MX	1.000	0.997	0.992	0.533	1.000	0.998	23.44	7.80	1.60	0.33	25.04	8.13	78.12	26.01	5.35	1.09	83.47	27.11
Egg Trans C - 2000 - CR	1.000	0.694	1.000	0.473	1.000	0.746	10.54	2.07	3.95	0.44	14.49	2.51	35.15	6.89	13.17	1.47	48.32	8.36
Egg Trans C - 4000 - CR	0.999	0.773	1.000	0.712	1.000	0.856	10.67	2.24	6.89	0.84	17.56	3.09	35.55	7.48	22.97	2.81	58.52	10.29
Egg Trans C - 6000 - CR	1.000	0.844	1.000	0.787	1.000	0.905	11.37	2.17	10.02	1.09	21.39	3.26	37.91	7.22	33.39	3.64	71.30	10.87

Appendix C. (Continued)

Numerical Results of Management Scenarios

15% Fisheries Bycatch Mortality Mitigation

	Prob [Persistence]					
	30yrs - MX	60yrs - MX	30yrs - CR	60yrs - CR	30yrs - Meta	60yrs - Meta
No Ex Situ	1.000	0.822	0.973	0.419	1.000	0.837
Headstart - 2000 - MX	1.000	0.872	0.987	0.431	1.000	0.884
Headstart - 4000 - MX	1.000	0.881	0.981	0.468	1.000	0.892
Headstart - 6000 - MX	1.000	0.924	0.983	0.497	1.000	0.935
Headstart - 2000 - CR	1.000	0.849	0.999	0.594	1.000	0.879
Headstart - 4000 - CR	1.000	0.876	1.000	0.645	1.000	0.900
Headstart - 6000 - CR	1.000	0.851	1.000	0.620	1.000	0.870
Egg Trans A - 2000 - MX	1.000	0.905	0.984	0.476	1.000	0.915
Egg Trans A - 4000 - MX	1.000	0.957	0.986	0.548	1.000	0.963
Egg Trans A - 6000 - MX	1.000	0.973	0.988	0.578	1.000	0.978
Egg Trans A - 2000 - CR	0.999	0.849	1.000	0.653	1.000	0.876
Egg Trans A - 4000 - CR	1.000	0.909	1.000	0.801	1.000	0.936
Egg Trans A - 6000 - CR	0.999	0.914	1.000	0.834	1.000	0.943
Egg Trans B - 2000 - MX	1.000	0.924	0.989	0.468	1.000	0.935
Egg Trans B - 4000 - MX	1.000	0.977	0.986	0.575	1.000	0.981
Egg Trans B - 6000 - MX	1.000	0.989	0.986	0.606	1.000	0.991
Egg Trans B - 2000 - CR	1.000	0.881	1.000	0.737	1.000	0.912
Egg Trans B - 4000 - CR	1.000	0.921	1.000	0.862	1.000	0.950
Egg Trans B - 6000 - CR	1.000	0.961	1.000	0.931	1.000	0.980
Egg Trans C - 2000 - MX	1.000	0.935	0.988	0.505	1.000	0.947
Egg Trans C - 4000 - MX	1.000	0.976	0.991	0.570	1.000	0.981
Egg Trans C - 6000 - MX	1.000	1.000	0.999	0.707	1.000	1.000
Egg Trans C - 2000 - CR	1.000	0.896	1.000	0.771	1.000	0.927
Egg Trans C - 4000 - CR	1.000	0.938	1.000	0.902	1.000	0.965
Egg Trans C - 6000 - CR	1.000	0.965	1.000	0.959	1.000	0.990

	Nesting Female Abundance					
	30yrs - MX	60yrs - MX	30yrs - CR	60yrs - CR	30yrs - Meta	60yrs - Meta
No Ex Situ	14.74	4.70	1.93	0.46	16.67	5.16
Headstart - 2000 - MX	15.27	4.89	1.77	0.43	17.04	5.32
Headstart - 4000 - MX	15.35	5.48	1.90	0.48	17.25	5.96
Headstart - 6000 - MX	16.59	5.47	1.85	0.44	18.44	5.91
Headstart - 2000 - CR	14.24	4.78	3.07	0.58	17.31	5.36
Headstart - 4000 - CR	14.95	5.43	3.41	0.76	18.36	6.19
Headstart - 6000 - CR	14.77	4.71	3.50	0.71	18.27	5.42
Egg Trans A - 2000 - MX	17.53	6.22	1.91	0.50	19.44	6.72
Egg Trans A - 4000 - MX	21.37	8.13	1.92	0.45	23.29	8.57
Egg Trans A - 6000 - MX	25.63	10.74	1.96	0.43	27.59	11.17
Egg Trans A - 2000 - CR	14.51	5.12	3.62	0.70	18.13	5.82
Egg Trans A - 4000 - CR	15.59	5.31	5.59	0.99	21.18	6.29
Egg Trans A - 6000 - CR	15.51	5.11	7.58	1.43	23.09	6.54
Egg Trans B - 2000 - MX	17.83	6.49	1.90	0.42	19.73	6.91
Egg Trans B - 4000 - MX	23.66	9.05	2.02	0.49	25.68	9.54
Egg Trans B - 6000 - MX	26.70	11.16	1.96	0.54	28.66	11.70
Egg Trans B - 2000 - CR	14.51	5.25	4.69	0.85	19.20	6.10
Egg Trans B - 4000 - CR	15.37	5.45	7.97	1.49	23.34	6.94
Egg Trans B - 6000 - CR	15.41	5.44	11.10	2.24	26.51	7.67
Egg Trans C - 2000 - MX	18.41	6.97	1.89	0.51	20.30	7.48
Egg Trans C - 4000 - MX	23.24	9.48	1.92	0.47	25.16	9.95
Egg Trans C - 6000 - MX	29.63	14.93	2.20	0.56	31.83	15.49
Egg Trans C - 2000 - CR	15.00	4.89	5.34	0.96	20.34	5.85
Egg Trans C - 4000 - CR	14.84	5.35	9.07	1.73	23.91	7.08
Egg Trans C - 6000 - CR	15.64	5.88	13.03	2.78	28.67	8.66

	Adult Female Abundance					
	30yrs - MX	60yrs - MX	30yrs - CR	60yrs - CR	30yrs - Meta	60yrs - Meta
No Ex Situ	49.15	15.66	6.44	1.53	55.59	17.18
Headstart - 2000 - MX	50.91	16.30	5.89	1.43	56.80	17.73
Headstart - 4000 - MX	51.17	18.27	6.33	1.60	57.50	19.87
Headstart - 6000 - MX	55.30	18.23	6.17	1.48	61.47	19.70
Headstart - 2000 - CR	47.48	15.94	10.22	1.94	57.70	17.87
Headstart - 4000 - CR	49.83	18.10	11.37	2.52	61.20	20.62
Headstart - 6000 - CR	49.23	15.69	11.66	2.37	60.89	18.06
Egg Trans A - 2000 - MX	58.45	20.74	6.36	1.66	64.81	22.40
Egg Trans A - 4000 - MX	71.22	27.09	6.40	1.48	77.62	28.57
Egg Trans A - 6000 - MX	85.42	35.81	6.54	1.43	91.96	37.24
Egg Trans A - 2000 - CR	48.36	17.06	12.05	2.34	60.41	19.40
Egg Trans A - 4000 - CR	51.98	17.69	18.64	3.29	70.62	20.98
Egg Trans A - 6000 - CR	51.69	17.02	25.27	4.78	76.96	21.80
Egg Trans B - 2000 - MX	59.45	21.63	6.34	1.40	65.79	23.03
Egg Trans B - 4000 - MX	78.85	30.17	6.74	1.63	85.59	31.80
Egg Trans B - 6000 - MX	88.99	37.20	6.54	1.80	95.53	39.01
Egg Trans B - 2000 - CR	48.36	17.48	15.64	2.84	64.00	20.33
Egg Trans B - 4000 - CR	51.24	18.16	26.58	4.96	77.82	23.12
Egg Trans B - 6000 - CR	51.37	18.12	37.00	7.46	88.37	25.58
Egg Trans C - 2000 - MX	61.37	23.25	6.32	1.69	67.69	24.94
Egg Trans C - 4000 - MX	77.47	31.61	6.40	1.56	83.87	33.17
Egg Trans C - 6000 - MX	98.77	49.75	7.32	1.87	106.09	51.62
Egg Trans C - 2000 - CR	49.98	16.30	17.79	3.21	67.77	19.51
Egg Trans C - 4000 - CR	49.48	17.83	30.23	5.77	79.71	23.60
Egg Trans C - 6000 - CR	52.15	19.60	43.45	9.27	95.60	28.86

Appendix C. (Continued)

Numerical Results of Management Scenarios

20% Fisheries Bycatch Mortality Mitigation

	Prob [Persistence]					
	30yrs - MX	60yrs - MX	30yrs - CR	60yrs - CR	30yrs - Meta	60yrs - Meta
No Ex Situ	1.000	0.981	0.991	0.662	1.000	0.983
Headstart - 2000 - MX	1.000	0.991	0.997	0.692	1.000	0.991
Headstart - 4000 - MX	1.000	0.998	0.995	0.739	1.000	0.998
Headstart - 6000 - MX	1.000	0.995	0.995	0.737	1.000	0.995
Headstart - 2000 - CR	1.000	0.986	1.000	0.829	1.000	0.988
Headstart - 4000 - CR	1.000	0.982	0.999	0.853	1.000	0.987
Headstart - 6000 - CR	1.000	0.990	1.000	0.850	1.000	0.990
Egg Trans A - 2000 - MX	1.000	0.996	0.997	0.732	1.000	0.997
Egg Trans A - 4000 - MX	1.000	1.000	0.999	0.802	1.000	1.000
Egg Trans A - 6000 - MX	1.000	1.000	0.999	0.794	1.000	1.000
Egg Trans A - 2000 - CR	1.000	0.990	1.000	0.870	1.000	0.992
Egg Trans A - 4000 - CR	1.000	0.993	1.000	0.941	1.000	0.995
Egg Trans A - 6000 - CR	1.000	0.990	1.000	0.940	1.000	0.992
Egg Trans B - 2000 - MX	1.000	1.000	0.995	0.735	1.000	1.000
Egg Trans B - 4000 - MX	1.000	1.000	0.995	0.773	1.000	1.000
Egg Trans B - 6000 - MX	1.000	1.000	0.996	0.802	1.000	1.000
Egg Trans B - 2000 - CR	1.000	0.991	1.000	0.923	1.000	0.992
Egg Trans B - 4000 - CR	1.000	0.995	1.000	0.967	1.000	0.997
Egg Trans B - 6000 - CR	1.000	0.998	1.000	0.989	1.000	0.999
Egg Trans C - 2000 - MX	1.000	0.998	0.993	0.754	1.000	0.999
Egg Trans C - 4000 - MX	1.000	1.000	0.996	0.784	1.000	1.000
Egg Trans C - 6000 - MX	1.000	1.000	1.000	1.000	1.000	1.000
Egg Trans C - 2000 - CR	1.000	0.993	1.000	0.943	1.000	0.995
Egg Trans C - 4000 - CR	1.000	0.995	1.000	0.975	1.000	0.999
Egg Trans C - 6000 - CR	1.000	0.999	1.000	0.990	1.000	1.000

	Nesting Female Abundance					
	30yrs - MX	60yrs - MX	30yrs - CR	60yrs - CR	30yrs - Meta	60yrs - Meta
No Ex Situ	20.00	12.80	2.25	0.60	22.25	13.40
Headstart - 2000 - MX	22.32	13.47	2.57	0.71	24.89	14.19
Headstart - 4000 - MX	23.29	14.74	2.56	0.74	25.85	15.48
Headstart - 6000 - MX	23.84	15.60	2.46	0.68	26.30	16.28
Headstart - 2000 - CR	20.58	12.74	3.93	1.15	24.51	13.89
Headstart - 4000 - CR	21.01	12.71	4.41	1.28	25.42	13.99
Headstart - 6000 - CR	20.82	13.12	3.40	1.22	24.22	14.35
Egg Trans A - 2000 - MX	25.56	16.84	2.47	0.74	28.03	17.58
Egg Trans A - 4000 - MX	30.45	20.68	2.56	0.78	33.01	21.46
Egg Trans A - 6000 - MX	35.87	24.86	2.61	0.74	38.48	25.60
Egg Trans A - 2000 - CR	20.81	12.66	4.66	1.21	25.47	13.86
Egg Trans A - 4000 - CR	20.76	13.07	7.09	2.02	27.85	15.09
Egg Trans A - 6000 - CR	20.81	13.49	9.40	2.86	30.21	16.35
Egg Trans B - 2000 - MX	24.94	16.99	2.40	0.71	27.34	17.69
Egg Trans B - 4000 - MX	30.75	20.80	2.57	0.80	33.32	21.61
Egg Trans B - 6000 - MX	34.19	24.06	2.49	0.74	36.68	24.80
Egg Trans B - 2000 - CR	21.61	14.33	6.20	1.67	27.81	16.00
Egg Trans B - 4000 - CR	20.60	13.56	9.78	2.85	30.38	16.41
Egg Trans B - 6000 - CR	21.47	13.29	13.79	4.21	35.26	17.50
Egg Trans C - 2000 - MX	26.41	17.67	2.45	0.68	28.86	18.35
Egg Trans C - 4000 - MX	31.72	22.63	2.45	0.74	34.17	23.37
Egg Trans C - 6000 - MX	37.48	27.41	2.54	0.75	40.02	28.16
Egg Trans C - 2000 - CR	21.05	13.32	6.66	1.88	27.71	15.20
Egg Trans C - 4000 - CR	20.23	12.47	10.96	3.22	31.19	15.69
Egg Trans C - 6000 - CR	21.38	14.20	15.94	5.26	37.32	19.46

	Adult Female Abundance					
	30yrs - MX	60yrs - MX	30yrs - CR	60yrs - CR	30yrs - Meta	60yrs - Meta
No Ex Situ	66.67	42.67	7.51	1.98	74.18	44.66
Headstart - 2000 - MX	74.40	44.91	8.58	2.38	82.98	47.29
Headstart - 4000 - MX	77.64	49.15	8.54	2.45	86.18	51.60
Headstart - 6000 - MX	79.47	52.01	8.21	2.28	87.68	54.28
Headstart - 2000 - CR	68.61	42.46	13.09	3.83	81.70	46.29
Headstart - 4000 - CR	70.05	42.36	14.68	4.27	84.73	46.63
Headstart - 6000 - CR	69.39	43.75	14.66	4.07	84.05	47.82
Egg Trans A - 2000 - MX	85.20	56.13	8.24	2.46	93.44	58.59
Egg Trans A - 4000 - MX	101.50	68.94	8.52	2.59	110.02	71.54
Egg Trans A - 6000 - MX	119.57	82.87	8.69	2.46	128.26	85.34
Egg Trans A - 2000 - CR	69.35	42.19	15.55	4.03	84.90	46.22
Egg Trans A - 4000 - CR	69.20	43.57	23.64	6.72	92.84	50.29
Egg Trans A - 6000 - CR	69.38	44.96	31.34	9.52	100.72	54.48
Egg Trans B - 2000 - MX	83.12	56.62	8.01	2.36	91.13	58.98
Egg Trans B - 4000 - MX	102.49	69.35	8.58	2.68	111.07	72.02
Egg Trans B - 6000 - MX	113.97	80.21	8.29	2.47	122.26	82.68
Egg Trans B - 2000 - CR	72.02	47.77	20.67	5.55	92.69	53.32
Egg Trans B - 4000 - CR	68.66	45.21	32.60	9.50	101.26	54.71
Egg Trans B - 6000 - CR	71.55	44.30	45.98	14.03	117.53	58.33
Egg Trans C - 2000 - MX	88.02	58.90	8.17	2.26	96.19	61.16
Egg Trans C - 4000 - MX	105.72	75.45	8.15	2.47	113.87	77.91
Egg Trans C - 6000 - MX	124.93	91.37	8.39	2.54	133.32	93.91
Egg Trans C - 2000 - CR	70.16	44.38	22.21	6.27	92.37	50.65
Egg Trans C - 4000 - CR	67.42	41.55	36.52	10.74	103.94	52.29
Egg Trans C - 6000 - CR	71.28	47.35	53.13	17.52	124.41	64.87

Appendix C. (Continued)

Numerical Results of Management Scenarios

25% Fisheries Bycatch Mortality Mitigation

Prob [Persistence]

	30yrs - MX	60yrs - MX	30yrs - CR	60yrs - CR	30yrs - Meta	60yrs - Meta
No Ex Situ	1.000	0.994	0.998	0.899	1.000	0.994
Headstart - 2000 - MX	1.000	1.000	0.999	0.901	1.000	1.000
Headstart - 4000 - MX	1.000	1.000	0.996	0.911	1.000	1.000
Headstart - 6000 - MX	1.000	1.000	0.999	0.918	1.000	1.000
Headstart - 2000 - CR	1.000	0.999	1.000	0.958	1.000	0.999
Headstart - 4000 - CR	1.000	0.998	1.000	0.976	1.000	0.999
Headstart - 6000 - CR	1.000	1.000	1.000	0.964	1.000	1.000
Egg Trans A - 2000 - MX	1.000	0.999	0.996	0.903	1.000	0.999
Egg Trans A - 4000 - MX	1.000	1.000	0.998	0.945	1.000	1.000
Egg Trans A - 6000 - MX	1.000	1.000	0.997	0.933	1.000	1.000
Egg Trans A - 2000 - CR	1.000	0.998	1.000	0.974	1.000	0.998
Egg Trans A - 4000 - CR	1.000	1.000	1.000	0.991	1.000	1.000
Egg Trans A - 6000 - CR	1.000	0.999	1.000	0.992	1.000	0.999
Egg Trans B - 2000 - MX	1.000	1.000	0.998	0.920	1.000	1.000
Egg Trans B - 4000 - MX	1.000	1.000	0.997	0.937	1.000	1.000
Egg Trans B - 6000 - MX	1.000	1.000	1.000	0.959	1.000	1.000
Egg Trans B - 2000 - CR	1.000	0.999	1.000	0.987	1.000	0.999
Egg Trans B - 4000 - CR	1.000	1.000	1.000	0.999	1.000	1.000
Egg Trans B - 6000 - CR	1.000	1.000	1.000	1.000	1.000	1.000
Egg Trans C - 2000 - MX	1.000	1.000	0.996	0.928	1.000	1.000
Egg Trans C - 4000 - MX	1.000	1.000	0.999	0.933	1.000	1.000
Egg Trans C - 6000 - MX	1.000	1.000	1.000	1.000	1.000	1.000
Egg Trans C - 2000 - CR	1.000	1.000	1.000	0.985	1.000	1.000
Egg Trans C - 4000 - CR	1.000	1.000	1.000	0.998	1.000	1.000
Egg Trans C - 6000 - CR	1.000	1.000	1.000	0.999	1.000	1.000

Nesting Female Abundance

	30yrs - MX	60yrs - MX	30yrs - CR	60yrs - CR	30yrs - Meta	60yrs - Meta
No Ex Situ	27.47	26.59	3.43	1.37	30.90	27.96
Headstart - 2000 - MX	28.28	28.47	3.33	1.47	31.61	29.94
Headstart - 4000 - MX	30.19	29.96	3.27	1.46	33.46	31.42
Headstart - 6000 - MX	29.70	30.47	3.39	1.52	33.09	31.99
Headstart - 2000 - CR	28.05	25.96	5.54	2.54	33.59	28.50
Headstart - 4000 - CR	27.90	27.36	6.21	2.82	34.11	30.18
Headstart - 6000 - CR	27.49	26.29	6.13	2.87	33.62	29.16
Egg Trans A - 2000 - MX	32.87	32.28	3.39	1.47	36.26	33.75
Egg Trans A - 4000 - MX	38.74	39.25	3.53	1.48	42.27	40.73
Egg Trans A - 6000 - MX	44.16	45.61	3.51	1.54	47.67	47.15
Egg Trans A - 2000 - CR	28.48	27.33	6.51	2.84	34.99	30.17
Egg Trans A - 4000 - CR	28.74	26.81	9.58	4.63	38.32	31.44
Egg Trans A - 6000 - CR	28.62	27.15	12.78	5.84	41.40	32.98
Egg Trans B - 2000 - MX	32.75	32.41	3.30	1.44	36.05	33.85
Egg Trans B - 4000 - MX	39.90	41.42	3.59	1.56	43.49	42.98
Egg Trans B - 6000 - MX	44.79	46.45	3.54	1.44	48.33	47.89
Egg Trans B - 2000 - CR	28.57	27.47	7.97	3.81	36.54	31.28
Egg Trans B - 4000 - CR	27.69	26.92	12.97	6.32	40.66	33.24
Egg Trans B - 6000 - CR	27.97	26.51	17.69	8.89	45.66	35.40
Egg Trans C - 2000 - MX	35.54	33.68	3.51	1.44	39.05	35.12
Egg Trans C - 4000 - MX	40.21	41.14	3.41	1.40	43.62	42.54
Egg Trans C - 6000 - MX	46.96	48.99	3.54	1.49	50.50	50.48
Egg Trans C - 2000 - CR	27.51	25.91	8.77	4.08	36.28	30.00
Egg Trans C - 4000 - CR	28.75	28.20	14.87	7.42	43.62	35.61
Egg Trans C - 6000 - CR	28.21	27.10	20.37	10.72	48.58	37.82

Adult Female Abundance

	30yrs - MX	60yrs - MX	30yrs - CR	60yrs - CR	30yrs - Meta	60yrs - Meta
No Ex Situ	91.56	88.64	11.43	4.56	102.99	93.20
Headstart - 2000 - MX	94.27	94.91	11.10	4.91	105.37	99.82
Headstart - 4000 - MX	100.64	99.87	10.91	4.86	111.55	104.73
Headstart - 6000 - MX	98.99	101.57	11.29	5.07	110.28	106.64
Headstart - 2000 - CR	93.50	86.53	18.46	8.47	111.96	94.99
Headstart - 4000 - CR	93.00	91.20	20.69	9.40	113.69	100.60
Headstart - 6000 - CR	91.62	87.63	20.43	9.57	112.05	97.20
Egg Trans A - 2000 - MX	109.57	107.60	11.30	4.91	120.87	112.51
Egg Trans A - 4000 - MX	129.14	130.84	11.77	4.94	140.91	135.78
Egg Trans A - 6000 - MX	147.18	152.05	11.72	5.13	158.90	157.18
Egg Trans A - 2000 - CR	94.93	91.10	21.71	9.47	116.64	100.57
Egg Trans A - 4000 - CR	95.79	89.37	31.93	15.42	127.72	104.80
Egg Trans A - 6000 - CR	95.39	90.49	42.60	19.46	137.99	109.95
Egg Trans B - 2000 - MX	109.16	108.04	11.00	4.80	120.16	112.84
Egg Trans B - 4000 - MX	132.99	138.08	11.96	5.19	144.95	143.26
Egg Trans B - 6000 - MX	149.30	154.84	11.81	4.80	161.11	159.64
Egg Trans B - 2000 - CR	95.23	91.56	26.58	12.70	121.81	104.25
Egg Trans B - 4000 - CR	92.30	89.73	43.23	21.06	135.53	110.79
Egg Trans B - 6000 - CR	93.24	88.36	58.97	29.63	152.21	118.00
Egg Trans C - 2000 - MX	115.15	112.27	11.71	4.81	126.86	117.08
Egg Trans C - 4000 - MX	134.02	137.14	11.37	4.66	145.39	141.80
Egg Trans C - 6000 - MX	156.52	163.30	11.88	4.71	168.40	168.01
Egg Trans C - 2000 - CR	91.70	86.38	29.24	13.61	120.94	99.99
Egg Trans C - 4000 - CR	95.82	93.99	49.57	24.72	145.39	118.71
Egg Trans C - 6000 - CR	94.04	90.34	67.90	35.73	161.94	126.07

Appendix C. (Continued)

Numerical Results of Management Scenarios

30% Fisheries Bycatch Mortality Mitigation

	Prob [Persistence]					
	30yrs - MX	60yrs - MX	30yrs - CR	60yrs - CR	30yrs - Meta	60yrs - Meta
No Ex Situ	1.000	1.000	1.000	0.966	1.000	1.000
Headstart - 2000 - MX	1.000	1.000	1.000	0.977	1.000	1.000
Headstart - 4000 - MX	1.000	1.000	0.999	0.985	1.000	1.000
Headstart - 6000 - MX	1.000	1.000	1.000	0.980	1.000	1.000
Headstart - 2000 - CR	1.000	1.000	1.000	0.997	1.000	1.000
Headstart - 4000 - CR	1.000	1.000	1.000	0.997	1.000	1.000
Headstart - 6000 - CR	1.000	1.000	1.000	0.997	1.000	1.000
Egg Trans A - 2000 - MX	1.000	1.000	0.999	0.984	1.000	1.000
Egg Trans A - 4000 - MX	1.000	1.000	1.000	0.982	1.000	1.000
Egg Trans A - 6000 - MX	1.000	1.000	0.999	0.978	1.000	1.000
Egg Trans A - 2000 - CR	1.000	1.000	1.000	0.995	1.000	1.000
Egg Trans A - 4000 - CR	1.000	1.000	1.000	0.997	1.000	1.000
Egg Trans A - 6000 - CR	1.000	1.000	1.000	0.999	1.000	1.000
Egg Trans B - 2000 - MX	1.000	1.000	1.000	0.987	1.000	1.000
Egg Trans B - 4000 - MX	1.000	1.000	1.000	0.987	1.000	1.000
Egg Trans B - 6000 - MX	1.000	1.000	1.000	0.988	1.000	1.000
Egg Trans B - 2000 - CR	1.000	1.000	1.000	0.998	1.000	1.000
Egg Trans B - 4000 - CR	1.000	1.000	1.000	1.000	1.000	1.000
Egg Trans B - 6000 - CR	1.000	1.000	1.000	1.000	1.000	1.000
Egg Trans C - 2000 - MX	1.000	1.000	1.000	0.984	1.000	1.000
Egg Trans C - 4000 - MX	1.000	1.000	1.000	0.992	1.000	1.000
Egg Trans C - 6000 - MX	1.000	1.000	1.000	1.000	1.000	1.000
Egg Trans C - 2000 - CR	1.000	1.000	1.000	1.000	1.000	1.000
Egg Trans C - 4000 - CR	1.000	1.000	1.000	1.000	1.000	1.000
Egg Trans C - 6000 - CR	1.000	1.000	1.000	1.000	1.000	1.000

	Nesting Female Abundance					
	30yrs - MX	60yrs - MX	30yrs - CR	60yrs - CR	30yrs - Meta	60yrs - Meta
No Ex Situ	37.13	52.68	4.77	3.02	41.90	55.71
Headstart - 2000 - MX	37.61	52.86	4.61	2.88	42.22	55.74
Headstart - 4000 - MX	41.05	61.05	4.94	3.16	45.99	64.21
Headstart - 6000 - MX	40.80	60.98	4.58	2.94	45.38	63.92
Headstart - 2000 - CR	35.57	50.05	7.46	4.91	43.03	54.95
Headstart - 4000 - CR	36.22	51.13	8.44	6.09	44.66	57.22
Headstart - 6000 - CR	36.38	50.69	8.34	6.40	44.72	57.09
Egg Trans A - 2000 - MX	42.86	62.08	4.55	2.78	47.41	64.86
Egg Trans A - 4000 - MX	50.18	76.41	4.59	2.84	54.77	79.24
Egg Trans A - 6000 - MX	57.41	84.67	4.75	2.96	62.16	87.63
Egg Trans A - 2000 - CR	36.65	51.63	8.57	5.67	45.22	57.30
Egg Trans A - 4000 - CR	37.20	52.08	12.21	8.90	49.41	60.98
Egg Trans A - 6000 - CR	34.89	48.34	16.00	11.80	50.89	60.13
Egg Trans B - 2000 - MX	43.94	64.41	4.73	2.97	48.67	67.37
Egg Trans B - 4000 - MX	49.89	73.35	4.65	3.05	54.54	76.40
Egg Trans B - 6000 - MX	57.10	86.81	4.82	2.89	61.92	89.70
Egg Trans B - 2000 - CR	36.12	49.58	10.35	7.11	46.47	56.69
Egg Trans B - 4000 - CR	36.67	50.27	16.67	12.22	53.34	62.49
Egg Trans B - 6000 - CR	36.63	51.17	22.25	16.56	58.88	67.73
Egg Trans C - 2000 - MX	45.35	65.68	4.58	2.84	49.93	68.52
Egg Trans C - 4000 - MX	52.44	77.88	4.64	2.82	57.08	80.70
Egg Trans C - 6000 - MX	58.81	90.87	4.66	2.85	63.47	93.72
Egg Trans C - 2000 - CR	37.47	51.83	11.56	8.22	49.03	60.05
Egg Trans C - 4000 - CR	36.53	51.08	18.57	14.53	55.10	65.61
Egg Trans C - 6000 - CR	37.85	53.32	25.45	19.21	63.30	72.52

	Adult Female Abundance					
	30yrs - MX	60yrs - MX	30yrs - CR	60yrs - CR	30yrs - Meta	60yrs - Meta
No Ex Situ	123.76	175.61	15.89	10.08	139.65	185.69
Headstart - 2000 - MX	125.36	176.20	15.35	9.58	140.71	185.78
Headstart - 4000 - MX	136.82	203.49	16.46	10.55	153.28	214.04
Headstart - 6000 - MX	136.00	203.27	15.27	9.81	151.27	213.08
Headstart - 2000 - CR	118.57	166.82	24.87	16.36	143.44	183.18
Headstart - 4000 - CR	120.74	170.45	28.12	20.29	148.86	190.74
Headstart - 6000 - CR	121.28	168.97	27.79	21.32	149.07	190.29
Egg Trans A - 2000 - MX	142.88	206.93	15.17	9.28	158.05	216.21
Egg Trans A - 4000 - MX	167.26	254.69	15.31	9.45	182.57	264.14
Egg Trans A - 6000 - MX	191.35	282.22	15.83	9.88	207.18	292.10
Egg Trans A - 2000 - CR	122.16	172.11	28.55	18.90	150.71	191.01
Egg Trans A - 4000 - CR	124.01	173.61	40.70	29.67	164.71	203.28
Egg Trans A - 6000 - CR	116.29	161.12	53.33	39.33	169.62	200.45
Egg Trans B - 2000 - MX	146.45	214.68	15.75	9.90	162.20	224.58
Egg Trans B - 4000 - MX	166.31	244.49	15.51	10.17	181.82	254.65
Egg Trans B - 6000 - MX	190.33	289.36	16.07	9.64	206.40	299.00
Egg Trans B - 2000 - CR	120.40	165.28	34.49	23.70	154.89	188.97
Egg Trans B - 4000 - CR	122.22	167.57	55.56	40.74	177.78	208.31
Egg Trans B - 6000 - CR	122.09	170.55	74.18	55.21	196.27	225.76
Egg Trans C - 2000 - MX	151.17	218.92	15.25	9.46	166.42	228.38
Egg Trans C - 4000 - MX	174.81	259.59	15.46	9.41	190.27	269.00
Egg Trans C - 6000 - MX	196.03	302.90	15.66	9.44	211.69	312.34
Egg Trans C - 2000 - CR	124.89	172.77	38.55	27.39	163.44	200.16
Egg Trans C - 4000 - CR	121.77	170.26	61.89	48.42	183.66	218.68
Egg Trans C - 6000 - CR	126.16	177.73	84.82	64.02	210.98	241.75

Appendix C. (Continued)

Numerical Results of Management Scenarios

35% Fisheries Bycatch Mortality Mitigation

Prob [Persistence]

	30yrs - MX	60yrs - MX	30yrs - CR	60yrs - CR	30yrs - Meta	60yrs - Meta
No Ex Situ	1.000	1.000	1.000	0.995	1.000	1.000
Headstart - 2000 - MX	1.000	1.000	1.000	0.995	1.000	1.000
Headstart - 4000 - MX	1.000	1.000	1.000	0.998	1.000	1.000
Headstart - 6000 - MX	1.000	1.000	1.000	0.996	1.000	1.000
Headstart - 2000 - CR	1.000	1.000	1.000	0.999	1.000	1.000
Headstart - 4000 - CR	1.000	1.000	1.000	0.999	1.000	1.000
Headstart - 6000 - CR	1.000	1.000	1.000	1.000	1.000	1.000
Egg Trans A - 2000 - MX	1.000	1.000	1.000	0.997	1.000	1.000
Egg Trans A - 4000 - MX	1.000	1.000	1.000	0.998	1.000	1.000
Egg Trans A - 6000 - MX	1.000	1.000	1.000	1.000	1.000	1.000
Egg Trans A - 2000 - CR	1.000	1.000	1.000	1.000	1.000	1.000
Egg Trans A - 4000 - CR	1.000	1.000	1.000	1.000	1.000	1.000
Egg Trans A - 6000 - CR	1.000	1.000	1.000	1.000	1.000	1.000
Egg Trans B - 2000 - MX	1.000	1.000	1.000	0.991	1.000	1.000
Egg Trans B - 4000 - MX	1.000	1.000	1.000	0.998	1.000	1.000
Egg Trans B - 6000 - MX	1.000	1.000	1.000	0.999	1.000	1.000
Egg Trans B - 2000 - CR	1.000	1.000	1.000	1.000	1.000	1.000
Egg Trans B - 4000 - CR	1.000	1.000	1.000	1.000	1.000	1.000
Egg Trans B - 6000 - CR	1.000	1.000	1.000	1.000	1.000	1.000
Egg Trans C - 2000 - MX	1.000	1.000	1.000	1.000	1.000	1.000
Egg Trans C - 4000 - MX	1.000	1.000	1.000	0.995	1.000	1.000
Egg Trans C - 6000 - MX	1.000	1.000	1.000	1.000	1.000	1.000
Egg Trans C - 2000 - CR	1.000	1.000	1.000	1.000	1.000	1.000
Egg Trans C - 4000 - CR	1.000	1.000	1.000	1.000	1.000	1.000
Egg Trans C - 6000 - CR	1.000	1.000	1.000	1.000	1.000	1.000

Nesting Female Abundance

	30yrs - MX	60yrs - MX	30yrs - CR	60yrs - CR	30yrs - Meta	60yrs - Meta
No Ex Situ	46.84	94.66	6.17	5.71	53.01	100.37
Headstart - 2000 - MX	48.29	99.50	6.08	5.57	54.37	105.07
Headstart - 4000 - MX	50.46	102.69	5.99	5.25	56.45	107.95
Headstart - 6000 - MX	52.37	107.29	6.16	5.56	58.53	112.85
Headstart - 2000 - CR	47.95	93.62	9.80	9.73	57.75	103.35
Headstart - 4000 - CR	48.85	95.13	11.44	12.18	60.29	107.31
Headstart - 6000 - CR	47.40	97.22	11.46	12.68	58.86	109.90
Egg Trans A - 2000 - MX	54.60	115.07	6.16	5.48	60.76	120.54
Egg Trans A - 4000 - MX	64.12	135.95	6.55	5.97	70.67	141.93
Egg Trans A - 6000 - MX	73.38	155.76	6.32	5.72	79.70	161.48
Egg Trans A - 2000 - CR	46.53	89.74	11.24	10.97	57.77	100.71
Egg Trans A - 4000 - CR	46.76	93.18	15.35	15.56	62.11	108.75
Egg Trans A - 6000 - CR	47.36	96.45	19.92	21.21	67.28	117.66
Egg Trans B - 2000 - MX	55.68	118.03	6.27	5.81	61.95	123.84
Egg Trans B - 4000 - MX	63.60	127.34	6.17	5.66	69.77	133.00
Egg Trans B - 6000 - MX	72.97	152.85	6.26	5.68	79.23	158.53
Egg Trans B - 2000 - CR	47.48	95.64	13.49	14.09	60.97	109.73
Egg Trans B - 4000 - CR	48.49	99.17	21.12	22.08	69.61	121.25
Egg Trans B - 6000 - CR	47.40	94.38	27.80	29.81	75.20	124.18
Egg Trans C - 2000 - MX	57.68	118.75	6.24	5.39	63.92	124.13
Egg Trans C - 4000 - MX	66.05	136.54	6.08	5.62	72.13	142.15
Egg Trans C - 6000 - MX	76.75	169.47	6.22	5.58	82.97	175.05
Egg Trans C - 2000 - CR	47.46	90.76	14.65	14.84	62.11	105.60
Egg Trans C - 4000 - CR	49.17	100.73	23.42	24.42	72.59	125.15
Egg Trans C - 6000 - CR	48.41	96.34	31.78	34.33	80.19	130.67

Adult Female Abundance

	30yrs - MX	60yrs - MX	30yrs - CR	60yrs - CR	30yrs - Meta	60yrs - Meta
No Ex Situ	156.14	315.52	20.56	19.05	176.70	334.57
Headstart - 2000 - MX	160.98	331.67	20.27	18.55	181.25	350.23
Headstart - 4000 - MX	168.20	342.31	19.96	17.51	188.16	359.82
Headstart - 6000 - MX	174.57	357.63	20.54	18.53	195.11	376.16
Headstart - 2000 - CR	159.83	312.06	32.65	32.44	192.48	344.50
Headstart - 4000 - CR	162.83	317.10	38.13	40.59	200.96	357.69
Headstart - 6000 - CR	158.00	324.08	38.19	42.27	196.19	366.35
Egg Trans A - 2000 - MX	181.98	383.55	20.54	18.26	202.52	401.81
Egg Trans A - 4000 - MX	213.76	453.18	21.83	19.91	235.59	473.09
Egg Trans A - 6000 - MX	244.59	519.20	21.07	19.08	265.66	538.28
Egg Trans A - 2000 - CR	155.11	299.12	37.46	36.57	192.57	335.69
Egg Trans A - 4000 - CR	155.87	310.61	51.17	51.88	207.04	362.49
Egg Trans A - 6000 - CR	157.87	321.51	66.40	70.70	224.27	392.21
Egg Trans B - 2000 - MX	185.59	393.43	20.90	19.36	206.49	412.79
Egg Trans B - 4000 - MX	212.00	424.47	20.56	18.86	232.56	443.33
Egg Trans B - 6000 - MX	243.24	509.51	20.86	18.94	264.10	528.45
Egg Trans B - 2000 - CR	158.26	318.79	44.97	46.96	203.23	365.76
Egg Trans B - 4000 - CR	161.62	330.57	70.40	73.61	232.02	404.18
Egg Trans B - 6000 - CR	157.99	314.59	92.65	99.35	250.64	413.94
Egg Trans C - 2000 - MX	192.25	395.82	20.80	17.95	213.05	413.77
Egg Trans C - 4000 - MX	220.18	455.12	20.28	18.72	240.46	473.84
Egg Trans C - 6000 - MX	255.83	564.91	20.46	18.29	276.29	583.20
Egg Trans C - 2000 - CR	158.21	302.54	48.82	49.45	207.03	351.99
Egg Trans C - 4000 - CR	163.88	335.75	78.06	81.40	241.94	417.15
Egg Trans C - 6000 - CR	161.37	321.13	105.92	114.44	267.29	435.57

Appendix C. (Continued)

Numerical Results of Management Scenarios

40% Fisheries Bycatch Mortality Mitigation

Prob [Persistence]

	30yrs - MX	60yrs - MX	30yrs - CR	60yrs - CR	30yrs - Meta	60yrs - Meta
No Ex Situ	1.000	1.000	1.000	1.000	1.000	1.000
Headstart - 2000 - MX	1.000	1.000	1.000	1.000	1.000	1.000
Headstart - 4000 - MX	1.000	1.000	1.000	1.000	1.000	1.000
Headstart - 6000 - MX	1.000	1.000	1.000	1.000	1.000	1.000
Headstart - 2000 - CR	1.000	1.000	1.000	1.000	1.000	1.000
Headstart - 4000 - CR	1.000	1.000	1.000	1.000	1.000	1.000
Headstart - 6000 - CR	1.000	1.000	1.000	1.000	1.000	1.000
Egg Trans A - 2000 - MX	1.000	1.000	1.000	1.000	1.000	1.000
Egg Trans A - 4000 - MX	1.000	1.000	1.000	1.000	1.000	1.000
Egg Trans A - 6000 - MX	1.000	1.000	1.000	1.000	1.000	1.000
Egg Trans A - 2000 - CR	1.000	1.000	1.000	1.000	1.000	1.000
Egg Trans A - 4000 - CR	1.000	1.000	1.000	1.000	1.000	1.000
Egg Trans A - 6000 - CR	1.000	1.000	1.000	1.000	1.000	1.000
Egg Trans B - 2000 - MX	1.000	1.000	1.000	0.999	1.000	1.000
Egg Trans B - 4000 - MX	1.000	1.000	1.000	1.000	1.000	1.000
Egg Trans B - 6000 - MX	1.000	1.000	1.000	1.000	1.000	1.000
Egg Trans B - 2000 - CR	1.000	1.000	1.000	1.000	1.000	1.000
Egg Trans B - 4000 - CR	1.000	1.000	1.000	1.000	1.000	1.000
Egg Trans B - 6000 - CR	1.000	1.000	1.000	1.000	1.000	1.000
Egg Trans C - 2000 - MX	1.000	1.000	1.000	1.000	1.000	1.000
Egg Trans C - 4000 - MX	1.000	1.000	1.000	1.000	1.000	1.000
Egg Trans C - 6000 - MX	1.000	1.000	1.000	1.000	1.000	1.000
Egg Trans C - 2000 - CR	1.000	1.000	1.000	1.000	1.000	1.000
Egg Trans C - 4000 - CR	1.000	1.000	1.000	1.000	1.000	1.000
Egg Trans C - 6000 - CR	1.000	1.000	1.000	1.000	1.000	1.000

Nesting Female Abundance

	30yrs - MX	60yrs - MX	30yrs - CR	60yrs - CR	30yrs - Meta	60yrs - Meta
No Ex Situ	60.12	173.73	8.10	10.91	68.22	184.64
Headstart - 2000 - MX	61.98	176.70	8.20	11.04	70.18	187.74
Headstart - 4000 - MX	65.56	195.80	8.26	10.67	73.82	206.48
Headstart - 6000 - MX	66.56	197.19	8.33	10.58	74.89	207.77
Headstart - 2000 - CR	63.37	180.22	12.56	18.18	75.93	198.40
Headstart - 4000 - CR	62.90	182.43	14.83	22.85	77.73	205.28
Headstart - 6000 - CR	61.50	175.97	15.19	23.82	76.69	199.78
Egg Trans A - 2000 - MX	71.39	210.80	8.20	11.15	79.59	221.95
Egg Trans A - 4000 - MX	82.91	241.51	8.36	10.94	91.27	252.45
Egg Trans A - 6000 - MX	91.80	281.33	8.62	11.51	100.42	292.84
Egg Trans A - 2000 - CR	62.72	172.69	14.08	19.65	76.80	192.34
Egg Trans A - 4000 - CR	63.44	181.70	19.61	27.61	83.05	209.31
Egg Trans A - 6000 - CR	64.19	182.05	25.49	37.93	89.68	219.98
Egg Trans B - 2000 - MX	70.48	207.79	8.33	10.94	78.81	218.73
Egg Trans B - 4000 - MX	82.79	253.33	8.35	11.29	91.14	264.61
Egg Trans B - 6000 - MX	90.86	269.22	7.94	10.28	98.80	279.50
Egg Trans B - 2000 - CR	62.69	180.13	17.19	25.31	79.88	205.43
Egg Trans B - 4000 - CR	60.67	176.10	25.57	39.33	86.24	215.43
Egg Trans B - 6000 - CR	60.83	170.24	34.66	50.34	95.49	220.58
Egg Trans C - 2000 - MX	72.47	213.68	8.31	10.93	80.78	224.61
Egg Trans C - 4000 - MX	84.98	250.30	8.07	10.59	93.05	260.89
Egg Trans C - 6000 - MX	98.34	297.34	8.22	158.25	106.56	455.59
Egg Trans C - 2000 - CR	60.33	170.03	18.70	26.69	79.03	196.71
Egg Trans C - 4000 - CR	62.60	175.25	28.69	43.86	91.29	219.12
Egg Trans C - 6000 - CR	61.41	178.96	39.35	63.67	100.76	242.63

Adult Female Abundance

	30yrs - MX	60yrs - MX	30yrs - CR	60yrs - CR	30yrs - Meta	60yrs - Meta
No Ex Situ	200.40	579.09	27.01	36.36	227.41	615.45
Headstart - 2000 - MX	206.61	588.99	27.33	36.81	233.94	625.80
Headstart - 4000 - MX	218.54	652.68	27.54	35.58	246.08	688.26
Headstart - 6000 - MX	221.86	657.29	27.76	35.28	249.62	692.57
Headstart - 2000 - CR	211.24	600.72	41.85	60.60	253.09	661.32
Headstart - 4000 - CR	209.65	608.10	49.42	76.18	259.07	684.28
Headstart - 6000 - CR	205.01	586.56	50.64	79.38	255.65	665.94
Egg Trans A - 2000 - MX	237.96	702.66	27.34	37.17	265.30	739.84
Egg Trans A - 4000 - MX	276.35	805.03	27.87	36.48	304.22	841.51
Egg Trans A - 6000 - MX	306.01	937.76	28.73	38.36	334.74	976.12
Egg Trans A - 2000 - CR	209.08	575.62	46.95	65.50	256.03	641.13
Egg Trans A - 4000 - CR	211.48	605.66	65.36	92.03	276.84	697.69
Egg Trans A - 6000 - CR	213.96	606.83	84.96	126.43	298.92	733.26
Egg Trans B - 2000 - MX	234.94	692.63	27.75	36.48	262.69	729.12
Egg Trans B - 4000 - MX	275.98	844.42	27.84	37.62	303.82	882.04
Egg Trans B - 6000 - MX	302.85	897.41	26.46	34.25	329.31	931.66
Egg Trans B - 2000 - CR	208.97	600.43	57.28	84.35	266.25	684.78
Egg Trans B - 4000 - CR	202.22	587.00	85.25	131.09	287.47	718.09
Egg Trans B - 6000 - CR	202.78	567.46	115.53	167.80	318.31	735.26
Egg Trans C - 2000 - MX	241.57	712.25	27.71	36.44	269.28	748.69
Egg Trans C - 4000 - MX	283.27	834.35	26.90	35.30	310.17	869.64
Egg Trans C - 6000 - MX	327.78	991.13	27.25	527.51	355.03	1518.64
Egg Trans C - 2000 - CR	201.11	566.76	62.32	88.95	263.43	655.71
Egg Trans C - 4000 - CR	208.58	584.18	95.64	146.21	304.22	730.39
Egg Trans C - 6000 - CR	204.69	596.53	131.17	212.23	335.86	808.76

Supplemental Information: Details of *Vortex* Model Structure and Function

Figure S.1
Revised *Vortex* event sequence.

State Variable updates are added immediately after the Breed event in order to tally the number of nesting females before the year's mortality event. Another Population State Variable Update was inserted after the Supplementation event in order to tally the total number of eggs harvested and supplemented in the appropriate *ex situ* management scenarios, primarily for testing model performance. The Harvest event, where eggs are collected from the nesting beaches, is inserted immediately after Breed, while Supplement is inserted before the Age event in order to facilitate release of hatchlings before they age to one year.

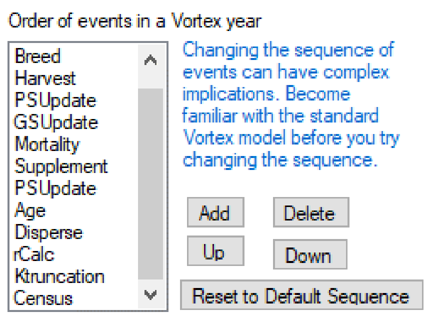
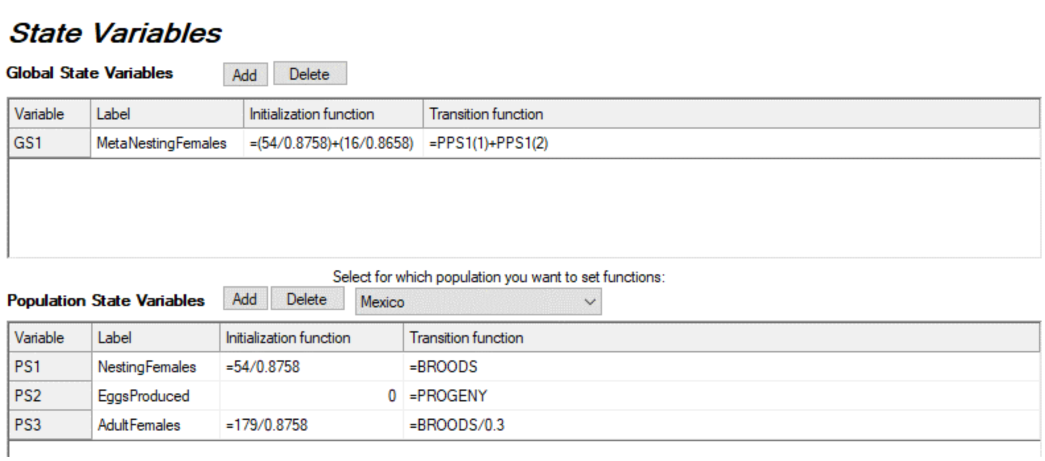


Figure S.2
Specification of State Variables defining initial conditions and output metrics.

Initial abundance of nesting females and total adult females is estimated by back-calculating the expected number the year prior to the start of the simulation, based on the observed growth rate (lambda) from the status quo scenario. This is required since the number of nesting females is tallied each year just after the breeding step at the beginning of the *Vortex* sequence of events, before mortality is imposed (see Figure S.1).

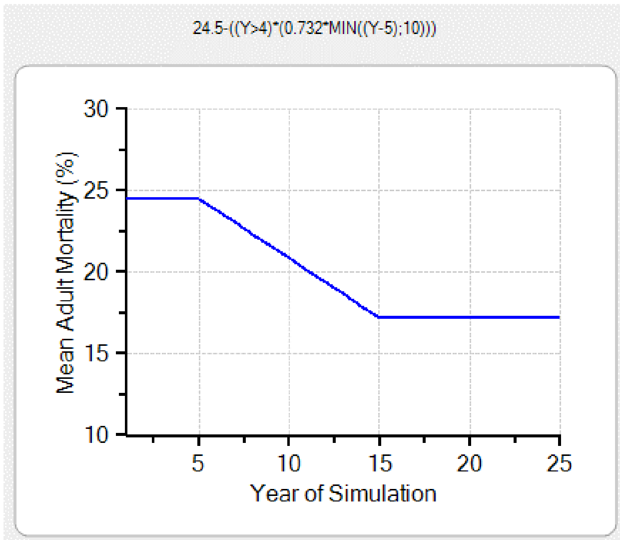
The Global State Variable tallying the combined number of nesting females across both subpopulations is required since *Vortex* by default calculates the average of any given Population State Variable for the metapopulation.



Supplemental Information (Contd)

Figure S.3
Specification of change in adult mortality through bycatch mitigation (Mexico subpopulation, 30% reduction in mortality).

Initial mortality rate of 24.5 is reduced proportionally across a 10-year period to 17.15%. Mitigation impacts begin in model year 5 and reach maximum impact in model year 15.



Supplemental Information (Contd)

Figure S.4
Specification of headstarting process.

(A): Addition of “holding population”. *Vortex* treats a headstarting process as a type of translocation, where individuals (in this case, eggs) are harvested from a given beach, transferred to a rearing facility (here designated “Incubation”), and then the surviving hatchlings are released offshore. Consequently, the intermediate Incubation “population” is specified for proper model function.

Number of populations: 3 — Reorder Populations (use with caution!)

	Population 1	Population 2	Population 3
Name	Mexico	Costa Rica	Incubation

(B): Egg harvest. Collection of eggs begins in model year 3 and continues annually for a total of 25 years. We assume that of the 6000 eggs collected in this scenario, 84% of them (5040 total) will be female.

The plot shows the mean annual survival of eggs from collection to release. Beginning in year 3, hatch rate is 0.5 and survival to release is 0.25. After five years of the headstarting program, these rates increase incrementally to 0.75 and 0.4, respectively. Therefore, early-program survival is expected to be approximately 12.5%, increasing to 30% by model year 8. Each survival rate includes a measure of stochastic variability – 0.07 for hatch rate and 0.04 for post-hatch survival to release.

Harvest

☑ Implement as Translocation? Percent survival during Translocation: =100*((Y>2)*(((0.5+(0.05*MIN((Y-3

☐ Use "Harvest" to set to 0 ISvar: 0

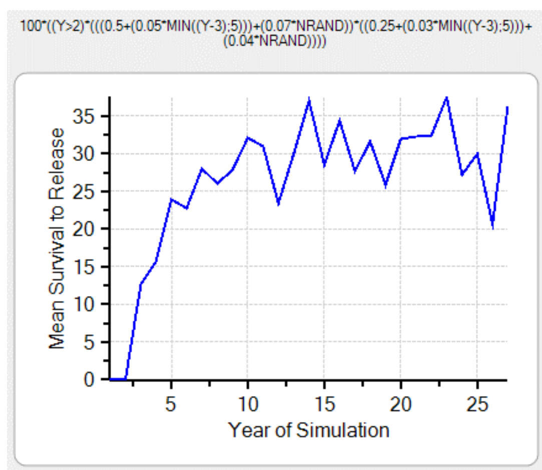
	Mexico	Costa Rica	Incubation
Population harvested?	☑	☐	☐
First year of harvest	3	0	0
Last year of harvest	27	0	0
Interval between harvests	1	0	0
Optional criteria for harvest	1	1	1

Number of females of each age to be harvested

	Mexico	Costa Rica	Incubation
Harvest from age 0 to 1	5040	0	0
Harvest from age 1 to 2	0	0	0
Harvest from age 2 to 3	0	0	0

Number of males of each age to be harvested

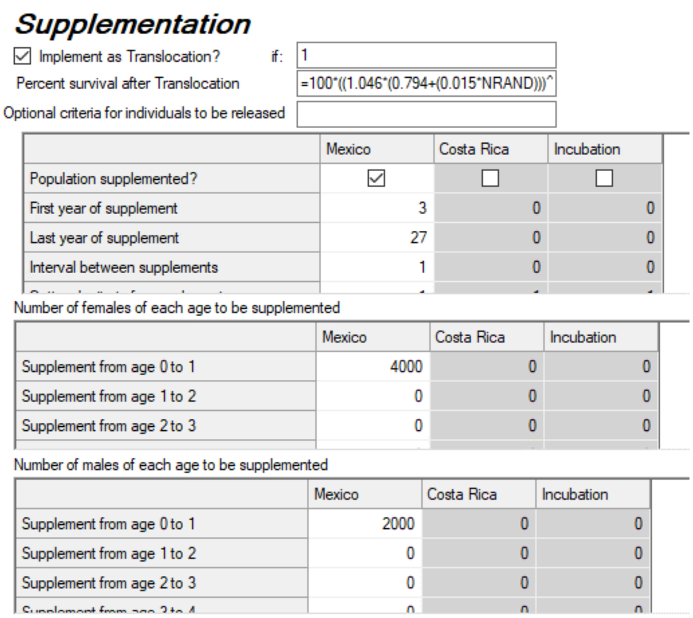
	Mexico	Costa Rica	Incubation
Harvest from age 0 to 1	960	0	0
Harvest from age 1 to 2	0	0	0
Harvest from age 2 to 3	0	0	0



Supplemental Information (Contd)

Figure S.4
Specification of headstarting process.

(C): Hatchling release. The specified number of individuals of each sex to be released are intentionally inflated simply to ensure that *Vortex* removes all headstarted individuals from the rearing facility each year. The plot shows the expected survival to one year of age among headstarted individuals that are released at three months of age. The value 0.794 is the expected mean monthly survival of wild-hatched individuals, given a total survival rate from egg to Age-1 of 0.063 used in the model. In the scenario, it is assumed that headstarted individuals will have a 50% greater survival to Age-1 than those hatched in the wild. This results from the proportional increase in monthly survival of 1.046 (improved monthly survival of 0.8305). Post-release survival rate includes a measure of stochastic variability equal to 0.015.



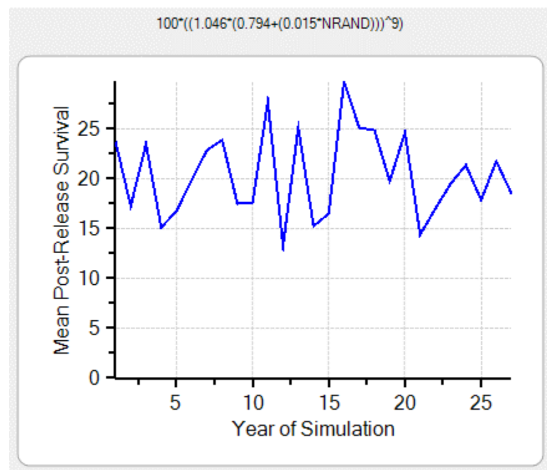
	Mexico	Costa Rica	Incubation
Population supplemented?	☑	☐	☐
First year of supplement	3	0	0
Last year of supplement	27	0	0
Interval between supplements	1	0	0

Number of females of each age to be supplemented

	Mexico	Costa Rica	Incubation
Supplement from age 0 to 1	4000	0	0
Supplement from age 1 to 2	0	0	0
Supplement from age 2 to 3	0	0	0

Number of males of each age to be supplemented

	Mexico	Costa Rica	Incubation
Supplement from age 0 to 1	2000	0	0
Supplement from age 1 to 2	0	0	0
Supplement from age 2 to 3	0	0	0

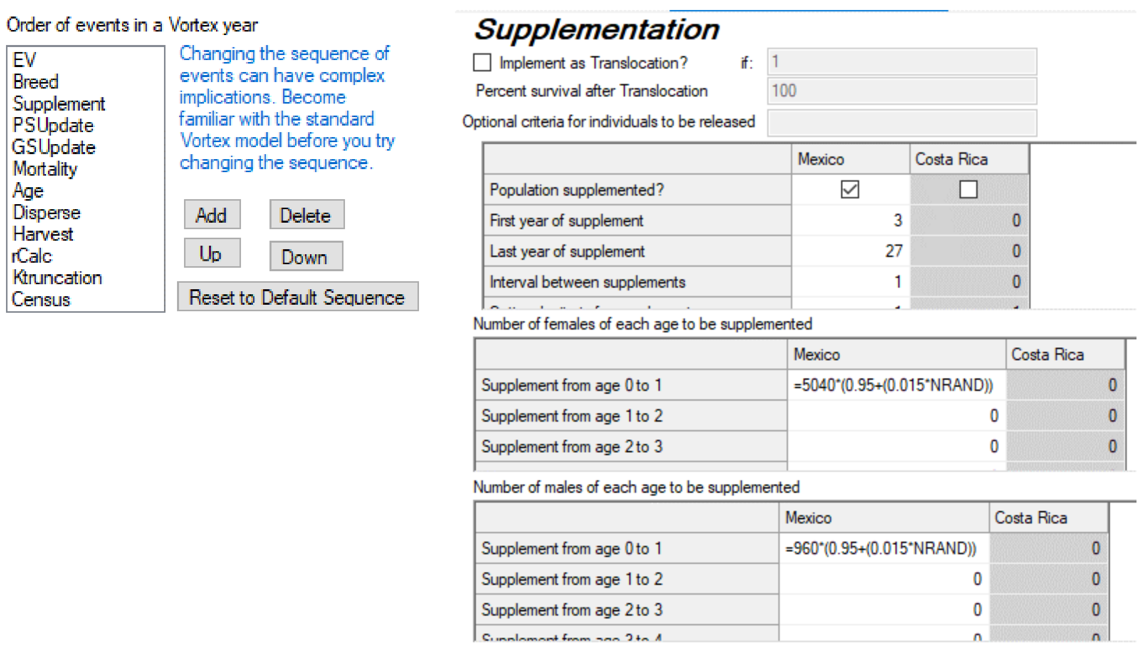


Supplemental Information (Contd)

Figure S.5
Specification of egg translocation process, Type A.

Note the addition of a Supplementation step immediately after the Breed event, simulating the addition of translocated eggs to those already deposited on the beaches in Mexico. As this egg translocation scenario is defined by depositing translocated eggs directly on to the beaches in Mexico, there is no need for an intermediate incubation/rearing facility as with the headstarting scenarios.

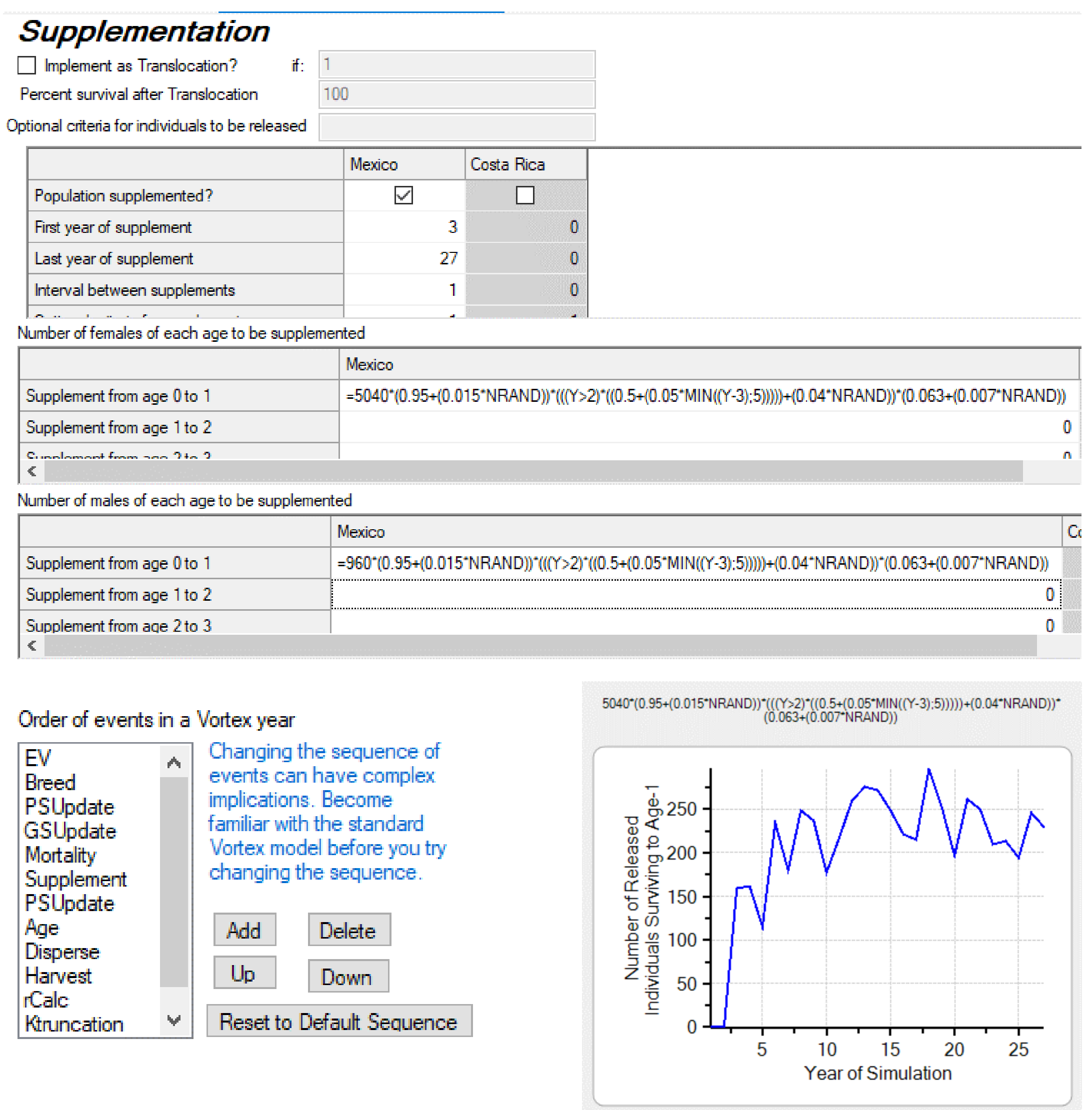
The numerical expression specifying the actual number of individuals supplemented to the population includes a mean egg survival rate following transportation from the source equal to 0.95±0.015.



Supplemental Information (Contd)

<u>Figure S.6</u>
Specification of egg translocation process, Type B.

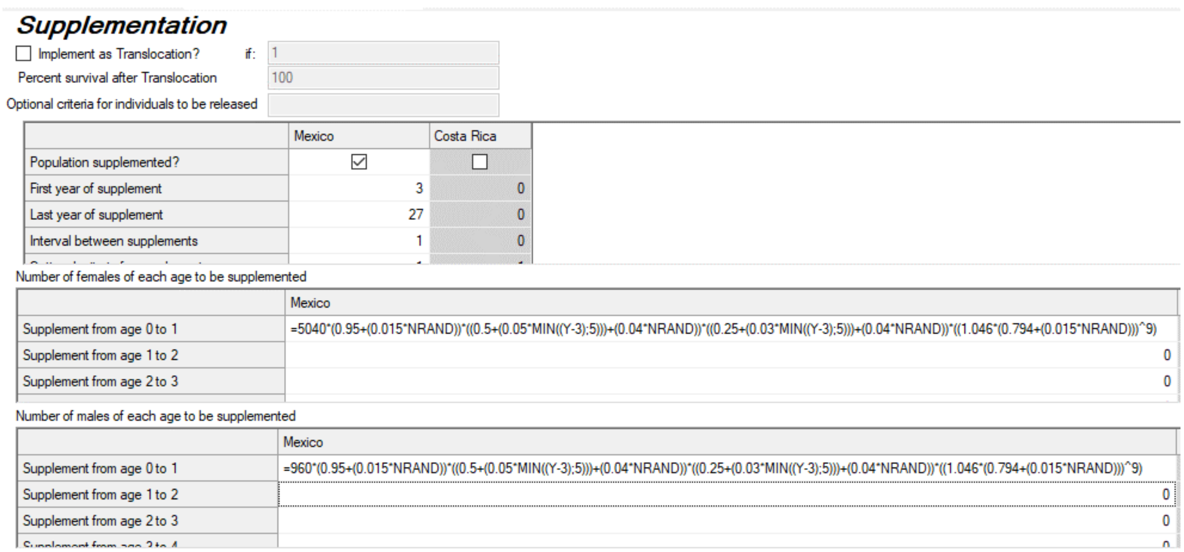
As with egg translocation Type A, these scenarios feature only the Supplementation step into the local population of interest.
Supplementation occurs after the Mortality event to simplify overall model structure. Consequently, the survival of translocated individuals after release from the rearing facility is accounted for in the actual specification of the number of individuals released (graphical representation of release function displayed in the plot below). Survival after transportation (0.95), hatching rate (0.5, increasing to 0.75 after five years), and first-year survival after hatching and release (0.063) are included in the supplementation function, with stochastic annual variability in those rates also added.
Note that, while the Harvest event is included in the event sequence, it is of no consequence as the explicit removal of individuals from any population of interest is not specified in the Harvest input screen.

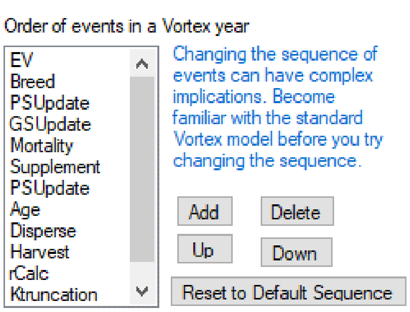


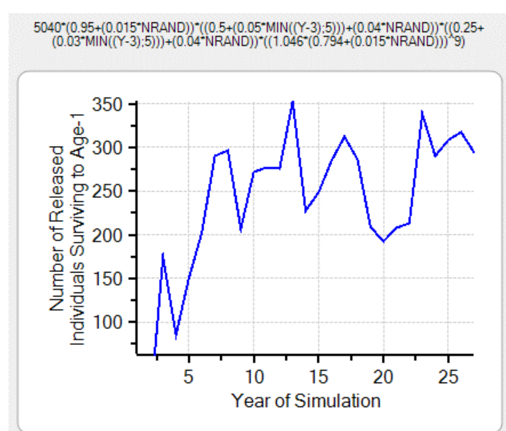
Supplemental Information (Contd)

Figure S.7
Specification of egg translocation process, Type C.

Mechanistically, egg translocation Type C is a combination of egg translocation Type B and Headstarting. Eggs from an external source are collected, transported to a rearing facility near Eastern Pacific nesting beaches, and the eggs are allowed to hatch. Hatchlings are cared for in the rearing facility for three months and then released.
The extensive function for the number of individuals supplemented accounts for transportation survival from the external source, hatching rate, survival of hatchlings to three months of age in the rearing facility, and post-release survival over nine months to one year of age. As in previous function expressions, survival includes increasing values for hatch rate and survival to three months of age in the rearing facility, and stochastic annual variability. As before, it is assumed that headstarted individuals will have a 50% greater survival to Age-1 compared to those hatched in the wild. This results from the proportional increase in monthly survival of 1.046 (improved monthly survival of 0.8305).
Note that, while the Harvest event is included in the event sequence, it is of no consequence as the explicit removal of individuals from any population of interest is not specified in the Harvest input screen.







APPENDIX I RESEARCH QUESTIONS IDENTIFIED BY WORKSHOP PARTICIPANTS

Health, husbandry and head-starting

- *Does increased sanitation in captivity affect the health of hatchlings compared with the natural environment?*
- *What egg sanitation protocols allow normal or improved hatching success and/or hatchling fitness?*
- *What defines a healthy captive hatchling and a healthy wild hatchling (microbiome studies, bloodwork, pathogen studies)?*
- *How do hatchlings acquire their microbiome?*
- *Do hatchlings fed an artificial diet have the same microbiome as those eating a natural diet?*
- *Can the microbiome be transplanted between animals?*
- *What are the known infectious diseases in source and destination nesting females?*
- *Are there differences in the health status of EP vs. Atlantic leatherback mothers and hatchlings?*
- *What is the pathology and microbiology of dead and weak hatchlings in the nest?*
- *Why do many hatchlings fail to thrive in captivity?*
- *What are the best husbandry and health conditions that would prevent the most common causes of mortality in head-started hatchlings?*
- *What are the environmental variables that we must replicate in captivity?*
- *Do we have to maintain individuals in captivity for 3-6 months before releasing?*
- *Do head-started hatchlings ultimately contribute to the reproductive population, whether translocated or not?*

Development and sex ratios

- *What influence does the incubation environment have on hatchling fitness?*
- *Why is leatherback hatching success so low?*
- *What are the causes of embryonic death?*
- *How do we develop incubation methodologies to improve hatching success and hatchling viability?*
- *What is the normal hatchling sex ratio?*
- *What is optimal hatchling sex-ratio for population recovery?*
- *How resilient to altered primary sex ratios is the adult population?*
- *Does a change in primary sex ratio result in a change in operational sex ratio?*

Early life stage translocation practices

- *When during development or after hatching do neonates imprint on their geomagnetic location?*
- *Does egg translocation affect migration patterns and/or location of foraging areas?*
- *What are the best criteria for identifying hatchlings for any captive-based studies?*
- *What are best practices for translocation in the field?*
- *Are there any lasting effects from chilling or hypoxia as a method to halt embryonic development and prevent movement-induced mortality during transportation of eggs?*
- *How long or how far can eggs be translocated without affecting developmental success?*
- *Is there a suitable source of Leatherback turtle population that could sustain the annual egg harvests proposed here (2000-6000 eggs annually) for translocation to the EP?*

Dispersal and early survival

- *What is the normal dispersal behaviour of hatchlings as they move offshore?*
- *If any turtles are in temporary captivity, where should they be released to optimize their survival?*
- *Do head-started and incubated hatchlings disperse in the same way as those raised in situ?*
- *Do hatchling and juvenile leatherbacks respond to different magnetic signatures or other cues with directional swimming? Are there other environmental variables they respond to such as water temperature or ocean circulation?*
- *What are the habitats used by neonate EP leatherbacks?*
- *What is the survival of head-started hatchlings, both during captive rearing and post-release?*
- *What is the actual survival rate of hatchlings as they disperse and over the first years of life?*
- *What is the nearshore predation risk and how can it be reduced?*
- *Does larger body size change chances of survival?*

Genetics

- *What are the genetic differences among different populations that might affect survival of animals translocated from one location to another?*
- *How does physical distance between source and recipient populations affect their genetic similarity or difference?*
- *How genetically diverse are Eastern Pacific populations compared with Atlantic/Caribbean populations?*
- *What effect will mixing of genetic stocks have if eggs or hatchlings are translocated among populations?*
- *What is the effect on the source population genetic diversity if eggs or hatchlings are removed for translocation?*

Socio-politics and public engagement

- *What is the likely social and political support for ex situ conservation actions?*
- *How can ex situ conservation be linked with environmental education?*
- *What is the best way to introduce ex situ management and to then engage local communities, governments and researchers with ex situ work?*
- *Who would fund ex situ conservation, and would this compete with funding for in situ conservation, especially bycatch mitigation work?*
- *How can ex-situ management contribute to building local capacity and job creation?*

APPENDIX II FACTS, ASSUMPTIONS AND KNOWLEDGE GAPS: EX SITU AND IN SITU

Facts, assumptions and knowledge gaps relevant to *ex situ* management.

Facts	How do we know about it?
There are multiple studies now that show that mothers differ in the quality of their clutches.	Studies from limited locales (2 Costa Rica for EP leatherbacks, and 2 from Florida (NW Atl. RMU).
Fact (assumption?): Translocation of >100 leatherback clutches from one ocean basin to another for an extended period of years has not been conducted	Translocation of leatherback egg clutches at the scale described in the models has not been conducted anywhere.
Fact (assumption?): At present, there are no facilities in countries with EP leatherback nesting capable of handling the number of turtles in captivity that the models currently describe	I might be unaware of such a place (someone please correct me if I am wrong!), but while there are a few places where turtles can be rehabilitated in captivity currently, there is not a facility capable of raising 1000s of hatchlings for 3 months, currently.
Fact: Sea turtle eggs have only a limited window of time to be relocated (= moved from the original nest to another incubation site) and still be viable. Vibration or rotating movements can kill the embryos that already are attached to the inner side of the eggshell. The implications of this for a potential egg translocation program across ocean basins, even in the narrow part of the continent (e.g., Costa Rica) are extremely important and would imply nightmarish logistics/ costs... Can something like that be achieved in a window of 2 hours? Has the model considered the unavoidable decrease in survival of the eggs during transportation?	You can start with Limpus et al. 1979. Miller & Limpus 1983.
In Western Australia we have moved sea turtle eggs (greens, loggerheads, flatbacks, not leatherbacks) from nesting beaches immediately following oviposition to incubators in my lab over distances up to 2500 km. We generally complete egg movement within 48 hours but have also found that eggs can be moved and remain viable even if they are in transit over 4 days. Eggs are kept cool in ice chests or portable refrigerators, and have been transferred by sea plane, road, and then 1-2 commercial flights. So, I think egg movement is feasible, especially with added measures such as maintaining eggs in hypoxia during transit [Nikki Mitchell]	We have described egg movements in a few of our papers, e.g. Stubbs, J. L., & Mitchell, N. J. (2018). The influence of temperature on embryonic respiration, growth, and sex determination in a Western Australian population of green turtles (*Chelonia mydas*). Physiological and Biochemical Zoology, 91(6), 1102-1114; Tedeschi, J. N., Kennington, W. J., Tomkins, J. L., Berry, O., Whiting, S., Meekan, M. G., & Mitchell, N. J. (2016). Heritable variation in heat shock gene expression: a potential mechanism for adaptation to thermal stress in embryos of sea turtles. Proceedings of the Royal Society B: Biological Sciences, 283(1822), 20152320; Stubbs, J. L., Kearney, M. R., Whiting, S. D., & Mitchell, N. J. (2014). Models of primary sex ratios at a major flatback turtle rookery show an anomalous

	masculinising trend. Climate Change Responses, 1(1), 1-18.
Sea turtle populations show variation in threshold temperatures for sex determination and embryonic survival. Data available for leatherbacks on these thresholds appear to be limited (but hopefully I am wrong). It would be ideal if equivalence (or otherwise) of pivotal temperatures between EPLB and any LB candidate source population was understood before any *ex situ* actions would be attempted.	Bentley, B. P., Stubbs, J. L., Whiting, S. D., & Mitchell, N. J. (2020). Variation in thermal traits describing sex determination and development in Western Australian sea turtle populations. Functional Ecology, 34(11), 2302-2314.;
The fact listed above currently we can use genetic techniques to manage diversity needs to be amended as I think there was some miscommunication from our conversation to what was written. To help clarify-in situations where captive breeding is occurring, this can be done where the genetics of the potential parents are examined ahead of time and that information is used to avoid close kin or otherwise potentially genetically compromised individuals from being selected for M/F pairs. However, that is not what is being proposed here-with egg collection we have no control over determining the parents. We CAN use genetic/kinship techniques to examine relationships afterwards (i.e., sampling either the nesting mothers directly or extracting DNA from the shell albumin, and then emerging hatchlings to reconstruct paternity). However, at this point we would have already moved and brought the hatchlings through development so it is challenging to know what would be done with that information after (if the hatchlings were very inbred, would they not be released?). One thing that could be done is if an appropriate database (based on genetics and/or tags) existed for the source beach population, one could try to avoid taking multiple nests from the same mother or from sisters.	Many; Stewart/Dutton 2011, 2014 are good examples - https://doi.org/10.1371/journal.pone.0088138 ; https://link.springer.com/article/10.1007/s10592-011-0212-2 ; Shamblin papers for sampling maternal DNA from eggshells

Fact: there are examples of translocations from other taxa in the literature and resources for guidelines. Importantly: 1) these are typically recommended in the context of genetic rescue where there is demonstrated negative consequences of inbreeding on population viability, often at least in part due to recent anthropogenic habitat fragmentation (which is distinctly different from the proposed scenarios), and 2) there remain disagreements/debate about what constitutes best practices among experts, in part driven by unknowns/difference among taxa and other factors of uncertainty. Nonetheless, two key components of guidelines may be particularly pertinent for these scenarios: 1) it is important to identify appropriate source populations that are not too divergent from the recipient population to avoid outbreeding depression and other issues if populations are locally adapted or otherwise have genetic incompatibilities, 2) it is important to have a good handle on the current and historical context of genomic diversity, inbreeding/ inbreeding depression issues in the target recipient population (as well as the source; see unknowns below).	(1) Bell et al. (2019). The exciting potential and remaining uncertainties of genetic rescue. TREE, 34, 1070–1079. (2) Frankham, R. (2015). Genetic rescue of small inbred populations: Meta-analysis reveals large and consistent benefits of gene flow. Molecular Ecology, 24, 2610–2618. (3) Fitzpatrick, S. W., & Funk, W. C. (2019). Genomics for genetic rescue. In O. P. Rajora (Ed.), Population genomics: Wildlife. Springer Nature Switzerland AG. (4) Edmands, S. (2007) Between a rock and a hard place: evaluating the relative risks of inbreeding and outbreeding for conservation and management Molecular Ecology 16, 463–475.
Fact (assumption): Estimates of divergence between Atlantic and Pacific leatherback populations are .17 median (i.e., 170,000 YA), CI 0.6-0.35 MYA (important to note the uncertainty in the estimates). This was done with mitochondrial genomes, and if there was mtDNA lineage replacement (nDNA genomes may have more divergence), then this would underestimate the actual divergence times (this analysis is planned for 2021 with whole nuclear genome data-Dutton, Komoroske et al.). A conservative approach would be to just use the dates of the closing of the Panama Isthmus, and go with theoretical isolation of Caribbean and East Pacific 1-3 MYA. I.e., these populations diverged a long time ago.	Duchene et al. 2012 Marine turtle mitogenome phylogenetics and evolution. Molecular Phylogenetics and Evolution.
Fact (with assumptions/unknown): Turtles relative to other taxa can have high synteny in their genomes despite long divergence times. It is not known how this would influence genetic incompatibilities by mixing populations with long divergence times. There is evidence in other sea turtles that some species can produce viable hybrids despite substantial divergence timescales, though there is recent evidence hybrids have lower fitness.	Komoroske/Mazzoni/Dutton-in prep (genome synteny); Arantes et al. Genomic evidence of recent hybridization between sea turtles at Abrolhos Archipelago and its association to low reproductive output. Scientific Reports. https://www.nature.com/articles/s41598-020-69613-8

Unknown: The state of genomic diversity, inbreeding levels, local adaptation (e.g., inherited navigational maps, pivotal sex determination temps, etc.), and potential genomic erosion or resiliency that would be critical to informing *ex situ* efforts is currently being studied but it not known for EP leatherbacks, or potential source populations	We have some preliminary analyses but need much more to make robust assessments. Related to Nicki's comment above-if anyone else knows of LA studies of pivotal temps across leatherback pops, please add
Population viability analysis (PVA) can be used to inform whether egg collections from any potential source population would be 'sustainable'. By sustainable, I mean not significantly increasing extinction risk for the source population or significantly reducing population abundance (say >5%).	PVA models are commonly used to inform conservation planning. Phil Miller's approach used in this workshop process could be replicated for any potential source population to inform whether they could / should be used as a source.
Just to add some more to the comments above from Ana B & Nicki M about egg translocations and embryonic mortality: There are proven techniques that can mitigate movement-induced embryonic mortality in sea turtle eggs. As Nicki mentions, the long-standing practice (since the 80s) of chilling eggs during transportation is effective to protect eggs from this threat (see Limpus et al publications for original methodology description). Recently, we have also shown that placing eggs into hypoxia, using cheap and simple vacuum-sealed bags, within 12 h of oviposition protects them from movement induced mortality during transport. We have now proven this technique on 5 species of sea turtle including leatherback sea turtles. Eggs can be maintained in hypoxia for long periods and still successfully hatch (up to 15 days). The only data we have from leatherback turtles is from a study using eggs from five different mothers which showed hatchings success of 32% if eggs were maintained for 3 days in hypoxia, a ~50% reduction in hatching success when compared with the control eggs in this experiment (hatching success 72%). However, I believe that most egg translocations, even from distant populations, could be achieved well within 48 hours. When eggs are chilled or kept in hypoxia for less time, hatching success is closer to normal. Pilot studies and/or first phases of any such program would greatly inform and refine timings and logistics of any such translocations.	Miller & Limpus (1983) A method for reducing movement-induced mortality in turtle eggs. http://www.seaturtle.org/mtn/archives/mtn26/mtn26p10.shtml Williamson et al (2017) Hypoxia as a novel method for preventing movement-induced mortality during translocation of turtle eggs. Biol. Cons. https://www.sciencedirect.com/science/article/abs/pii/S0006320717310856 Williamson (2018) Control and ecological significance of embryonic development in crocodiles and turtles. PhD Thesis https://www.researchgate.net/profile/Sean_Williamson3/publication/322465330_Control_and_ecological_significance_of_embryonic_development_in_turtles_and_crocodiles/links/5a599633a6fdcc3bfb5abc58/Control-and-ecological-significance-of-embryonic-development-in-turtles-and-crocodiles.pdf

Vacuum-sealed bags are cheap and easy to use for egg transportation. The only significant cost for translocation would be ground and/or air transport, which would vary depending upon where the source and sink nesting beaches were located. For example, translocation from Panama or Costa Rica to Costa Rica would potentially require a short flight or longer drive (<12 h). Further distances, say Grenada to Mex or CR or Africa to CR / Mex, would require greater expenses for flights to achieve transportation within a 48 window.	Assuming 110 nests = 6000 eggs = 80 g per egg x 6000 = approx. 480 kg of eggs (excluding SAGs): - Reusable vacuum-sealed bags $USD 2 - 10 x 220 - $440 - 2200 total. Note if risks of cross-contamination are considered to be significant, then single-use bag options may be more advisable, or some other means to mitigate for this risk. - Ground transportation (van / truck) for 110 nests - $400 USD for 20ft refrigerated truckload Panama to Costa Rica x 10 trucks over a nesting season - $USD 4,000 - 12,000 total annual cost - if anyone has more accurate costings for ground freight costs in CR / Panama / Mex? - Air transportation (air freight) for 110 nests - approx. 10 flights over a nesting season - $500 for 50 kg fragile air freight - estimate $500 - $1500 USD per flight x 10 - $5k - 15k total annual cost.
Fact: there is a new tool available to help with decisions about *ex situ* conservation management. One such tool, PACES (Planning and Assessment for Conservation through Ex-Situ management), has been developed and tested on Australian case studies, and may become part of the IUCN CPSG toolbox. PVAs (such as those developed by Phil Miller for this workshop) can be used in conjunction with expert elicitation and costings data to populate decision nodes in the PACES tool.	PACES is not yet publicly available, but some details here: https://www.nespthreatenedspecies.edu.au/media/ytqf1crn/4-1-5-decision-tool-for-ex-situ-management-factsheet_v3.pdf. Developer Tracy Rout can provide a User Guide and Excel spreadsheets with instructions (t.rout2@uq.edu.au)
Novel pathogen transfer from source to sink populations can be mitigated by collecting eggs as they are being laid and avoiding eggs being contaminated with pathogens from the nest environment at the source location.	Patino-Martinez et al 2011 http://www.aranzadi.eus/wp-content/files_mf/1335524868PatinoMartinez2012_Criaderotortugaslaudinfeccionesmicroorganismos.pdf
We can successfully move eggs across different beaches within the same ocean basin (produce hatchlings= success). However, if eggs were moved across the Equator (e.g. North to South), they could remain in the same ocean basin, but there might be other implications for the success of the translocation.	

All leatherback populations are declining. Some populations are more abundant than in the Eastern Pacific.	Published assessments (e.g. RedList). The Southeast Atlantic breeding population in West Africa (e.g. Gabon, Equatorial Guinea, Nigeria, Cameroon, Ivory Coast) is considered "data deficient" but may be one of a few populations with positive lambda -- not in a state of decline. See recent work by Anna Ortega…
We can use genetic techniques to manage genetic diversity (parentage) of eggs collected for *ex situ* management.	
There are high levels of environmental and individual variation in egg productivity among females.	
Pathogens will be moved through translocation.	
We have a lot of husbandry experience around hatchling management that can be adapted to leatherbacks.	Work done in Malaysia, Florida, Costa Rica, Mexico, Texas…leatherbacks specifically and from other species (e.g. Kemps).

Assumptions	Why do we assume this?
There are proven husbandry practices that will result in the viable head-started progeny at the scale described for this project	Those that have reared leatherbacks please comment.
If leatherback turtles from the Atlantic are released in the Pacific and survive to adulthood, they will shift their nesting season to coincide with favorable nest incubation conditions (sand accretion/erosion cycles, temperature, humidity)	Can we explore how non-sea turtle species have adjusted their nesting timing / periodicity to coincide with the appropriate environmental conditions?
Leatherbacks translocated from other ocean basins and released in the Pacific will have the navigational ability/repertoire to survive and find food	We do not know if this is true. Critical discussion and invoking of knowledge from the animal world needed here.
The husbandry experience from hard-shelled turtles is a start, but VERY LIMITED. Hard-shelled species are tough. In contrast, working with leatherbacks in captivity is like working with babies in ICU. They are extremely fragile, and interventions often are not obvious in time to help.	I have almost 25 years of experience with leatherback husbandry and pathology (I shared our husbandry approaches with rehab centers). See Miller et al. 2009.

95% of eggs will survive translocation is optimistic	Given the above about the scale of the required translocation, the assumption that nearly no eggs would die because of large-scale movements seems optimistic
High survival of head-started juveniles following release is optimistic	Survival in the wild is complicated, and having been raised in a captive setting does not necessarily prepare animals for confronting challenges in the wild (changing environmental conditions, finding food, evading predators, eventually navigating back to breeding/nesting areas); I think I saw Brian Stacy make this point in the chat during one of the sessions
We can use genetic techniques to manage genetic diversity of eggs during the translocation program	I am not sure what the statement means, but we do not have enough knowledge of the leatherback's genetic diversity to attempt to "manage" the parenting across ocean basins, not in the way it is done with the Mexican wolf, for example...
The ontogenetic migration of sea turtle migrations is driven by ocean currents (Hays et al. 2010).	In "Ontogeny of long distance migration" Scott et al. (Ecology, 2014) provided evidence that the "migration routes of adult turtles are strongly related to hatchling drift patterns, implying that adult migration goals are learned through their past experiences dispersing with ocean currents. The diverse migration destinations of adults consistently reflected the diversity in sites they would have encountered as drifting hatchlings. Their findings "reveal how a simple mechanism, juvenile passive drift, can explain the ontogeny of some of the longest migrations in the animal kingdom and ensure that adults find suitable foraging sites." Note, there are significant suppositions in the Scott et al 2014 paper- See "On the dispersal of leatherback turtle hatchlings from Mesoamerican nesting beaches" doi:10.1098/rspb.2011.2348, Shillinger et al. Proc. R. Soc. B (2012) 279, 2391–2395 and "Oceanic dispersal of juvenile leatherback turtles: going beyond passive drift modeling" doi: 10.3354/meps09689, Gaspar, P., Benson SR, et al. MEPS Vol.

	457: 265–284, 2012.
Natal homing - Adults will head back to reproduce in their natal area of which they have imprinted the magnetic coordinates.	Nobody knows exactly when imprinting takes place, but Kemp's Ridley were successfully translocated from Mexico to Padre Island National Park. The Kemps hatchling translocation protocol (see papers by Donna Shaver et al). In addition if one takes eggs/hatchlings from the Atlantic coast of Costa-Rica one can imagine that even if imprinting has occurred on the coordinates of the Atlantic beach, navigation back to this beach will automatically lead translocated turtles along the Pacific coast of Costa-Rica (at a similar latitude because navigation is done using the Earth magnetic field intensity and/or inclination and both intensity and inclination take very similar values along the Atlantic and Pacific side of Costa Rica. So the probability of successful natal homing shall be high.

Juveniles engage in geomagnetic imprinting. Young turtles progressively "learn" the magnetic characteristics of the areas that they visit (i.e. they progressively build their own magnetic map of their environment as they discover it during their pelagic juvenile phase). They later use this information to navigate back towards previously encountered favorable foraging area (this makes foraging site fidelity possible). We can thus reasonably assume that hatchlings released in the Pacific will progressively learn the magnetic map of the Pacific.	There is substantial evidence to support the theory of geomagnetic imprinting in sea turtles. Among others, the following publications from the Lohmann Laboratory provide to substantiate this theory: Brothers, J. R. and K. J. Lohmann. 2018. Evidence that magnetic navigation and geomagnetic imprinting shape spatial genetic variation in sea turtles. Current Biology https://doi.org/10.1016/j.cub.2018.03.022, Lohmann, K. J., Putman, N. F., and C. M. F. Lohmann. 2008; Geomagnetic imprinting: a unifying hypothesis of long-distance natal homing in salmon and sea turtles. Proceedings of the National Academy of Sciences. 105: 19096-19101; Lohmann, K. J., Lohmann, C. M. F., Brothers, J. R., and N. F. Putman. 2013. Natal homing and imprinting in sea turtles. In: Biology of Sea Turtles (Editors: J. Wyneken, K. J. Lohmann, and J. Musick). Vol. 3, pp. 59-77. CRC Press: Boca Raton.; Brothers, J. R. and K. J. Lohmann. 2015. Evidence for geomagnetic imprinting and magnetic navigation in the natal homing of sea turtles. Current Biology. 25: 392-396. Putman, N. F. and K. J. Lohmann. 2008. Compatibility of magnetic imprinting and secular variation. Current Biology. 18: R596-597. We can thus reasonably assume that hatchlings released in the Pacific will progressively learn the magnetic map of the Pacific.
Turtles have evolved innate behavior to swim in "favorable directions" (e.g. directions that keep them safe) in regions where such behavior is advantageous	These results were presented by Lohmann et al (2009) in Science: "Hatchling loggerheads, when exposed to magnetic fields replicating those found in three widely separated oceanic regions, responded by swimming in directions that would, in each case, help keep turtles within the currents of the North Atlantic gyre and facilitate movement along the migratory pathway. These results imply that young loggerheads have a guidance system in which regional magnetic fields function as navigational markers and elicit changes in swimming direction at crucial

	geographic boundaries" More work on this has been done by Fuxjager, Eastwood & Lohmann (JEB, 2011) : "Hatchlings responded to fields that exist within the gyre currents by swimming in directions consistent with their migratory route at each location, whereas turtles exposed to a field that exists north of the gyre had an orientation that was statistically indistinguishable from random." These results are consistent with the hypothesis that loggerhead turtles entering the sea for the first time possess a navigational system in which a series of regional magnetic fields sequentially trigger orientation responses that help steer turtles along the migratory route. By contrast, hatchlings may fail to respond to fields that exist in locations beyond the turtles' normal geographic range. Further experimental work by Putman et al. (JEB, 2015) shows that (magnetic) fields that occur at locations that are neither dangerous nor unfavorable might not elicit strongly oriented swimming (Lohmann and Lohmann, 1994; Merrill and Salmon, 2010). Furthermore, Fuxjager et al. (2014, PRS B) showed that, in orientation experiments, hatchlings that developed in the normal ambient field oriented approximately south when exposed to a field that exists near the northern coast of Portugal, a direction consistent with their migratory route in the northeastern Atlantic. By contrast, hatchlings that developed in a distorted magnetic field had orientation indistinguishable from random when tested in the same north Portugal field. In short, this suggests that these loggerheads likely have evolved an innate capability to trigger swimming "in the good direction" in regions where they might otherwise be in danger. No swimming activity is elicited in safe areas or in areas beyond the turtle's "normal" range. In addition this directed swimming capability in "dangerous regions" seems to disappear if hatchlings are raised in a distorted magnetic field.

If NW Atlantic leatherbacks evolved a similar navigational behavior (to loggerheads) they might start swimming in "innate directions" if they happened to find, in the Pacific, magnetic fields with the same characteristics as in the Atlantic and corresponding to dangerous areas in the areas usually visited in the Atlantic.	Based on NWA juvenile leatherback dispersal simulations (Lalire and Gaspar, 2019), it appears that the most dangerous area is the northern end of the Gulf Stream (e.g. off Maine, USA). A quick look at magnetic field maps show that this dangerous area is characterized by high values of both the intensity AND the inclination of the Earth magnetic field, a combination one does not find in the South Pacific where hatchlings are expected to drift. Thus, it appears that such a behaviors would not be elicited in NWA leatherback hatchlings translocated in the Pacific. The most likely hypothesis is thus that these translocated hatchlings will never initiate directed swimming (in a direction that might be appropriate in the Atlantic but not in the Pacific). Also, if one considers that translocated hatchings have suffered from distortion of the magnetic field during incubation, and react like loggerheads to such perturbations, they might just be unable to undertake such directed swimming triggered by specific values of the magnetic field. Taken together, it seems very unlikely that the characteristics of the Earth magnetic field in the Pacific will all the sudden initiate inappropriate (dangerous) swimming activity in translocated hatchlings
Husbandry practices can be further refined to increase survival and fitness of leatherbacks raised to three months of age.	Upscaling of research and endeavours to maintain LBs in captivity should lead to improved knowledge and refinement of husbandry techniques
A new facility or multiple facilities would have to be built or an existing facility expanded to accommodate raising 1000-4500 hatchlings for 3 months annually.	To my knowledge, there are no facilities in the current nesting range of EPLBs close to nesting beaches that have capacity now
Because sea turtle nests are warm, moist and nutrient rich, they are likely to have an assemblage of microbes that may become pathogenic. The species on one coast will have evolved with their microbial environment. Those on another coast may not have the same relationships with the new local microbiome that will be present on the new locations of eggs (or turtles)	See Miller et al. 2009; Perhaps there are other papers?

Eggs can be relocated successfully in other sea turtle species so likely could be in this species	
Water quality parameters for sea turtles are known /rearing and husbandry related can be adapted to species	
Some pathology known for other species of sea turtles for pre-release health and pathology screening	
Tissue samples and other cryopreservation techniques know and assume capture of genetic material for cell line cultures for frozen zoo	
Paternity and kinship for genetic health assumptions can be made	
Techniques for marking and telemetry know for this and similar species - post release animals can be monitored post release	
It may be difficult to translocate across ocean basins.	
We could do translocation better with 'doomed eggs'.	
We have fluctuating, inconsistent sources of eggs for translocation.	
There is concern about mixing genetic stock across ocean basins.	
We might be able to target specific 'successful' females for prioritising egg collection.	
We can reduce environmental variation in egg development through proper husbandry.	
Navigational capacity of individuals translocated across ocean basins?	Ken Lohmann's work- is this work applicable across species and basins?

Knowledge gaps	How could we fill this gap?
Do we know what enough genetic diversity is? The minimum population size estimators rarely are developed for long-lived later maturing species.	Perhaps Lisa K. can comment. Do the Vortex models address this issue? The Lande, Shaffer, and Charlesworth papers from nearly 2-3 decades ago set the stage.
What permits would be required for each ex situ scenario? How likely are management authorities to provide such permits?	J. Seminoff: We need to engage with nations sooner than later to evaluate the feasibility of government buy-in
What would the perception of such measures be by the public? Local communities? Existing conservation groups, particularly those that are resource limited, and perhaps working on species with a higher chance of conservation success with similar investments?	
What is the number of eggs/head-started turtles that would stabilize the population trajectory on its own, or with low to moderate levels of bycatch mortality reduction?	6000 eggs is the highest value examined thus far in the model results presented, and depending on the assumptions about hatching success, survival in captivity, and post-release survival, benefits to the population are ambiguous. So how many more eggs are needed to produce a clearly positive benefit?
How equitable would it be to invest a ton of money, infrastructure, and resources in a 'hail Mary' effort to translocate eggs long distances and/or raise turtles in captivity for many years in low and middle-income countries already challenged by insufficient resources? Should those who would propose ex situ measures be concerned about a perception of ‘conservation colonialism' among communities in countries where such measures would be proposed, given enormous resources coming from high-income countries in support of conservation values of those people from those countries?	Not sure if this has come up yet, but it is important to consider the equity issues implied by the motivations and resources involved with ex situ conservation. To be honest, I worry about this for the conservation work we already do. This is another reason why it is essential to implement conservation that is culturally respectful and appropriate and should improve the livelihoods of people affected by the conservation actions.

Considering that funding for conservation in general is insufficient for the need--EP leatherbacks and beyond--at what point would resources be better spent on conservation of other species/ecosystems? In other words, if ex situ actions are like a 'rescue mission' because everything else has apparently failed, are they worth it if the same funds could be spent on actions that might more effectively conserve other species/ecosystems?	Lots of good literature looking at these issues (e.g., Possingham group); i.e., inequitable distribution of funds and other resources to only some species (including sea turtles) when such funds could perhaps be spent more effectively on a wider or different range of species
We do not really know the feasibility of any potential donor population that can stand the extraction of 6,000 eggs along 20 years	I do not think we can talk about translocation procedures without making a serious analysis of the possible impact on any potential donor population.
Juvenile morphometric data	
Diet for juveniles in managed care	
Microbiome of sea turtles and comparison between wild populations and captive animals (for immune system health and disease resistance related)	
Disease risks incoming or outgoing	
Semen collection and fecundity levels/fertility levels of eggs in nests could be learned through this process- Techniques exist now to determine if turtle eggs and crocodilian eggs have been fertilized which can help improve egg fecundity/fertility/incubation via filling in knowledge gaps	
Fitness of releasable animals / where they go and how long they survive	
How do introduced genes impact population - introduced defects or increased vigor with new haplotypes?	
Proper source location for translocated eggs?	Detailed assessment of individual source candidates
Political uncertainty around source viability?	

Facts, assumptions and knowledge gaps relevant to *in situ* management.

Facts	How do we know about it?
There are several existing/developing mitigation measures that have shown significant reduction in sea turtle bycatch (in some cases in leatherbacks) in net and longline fishing gear, while maintaining target catch rates	Several papers, see 'relevant literature' folder
Threats to nesting females and their eggs and hatchlings have been reduced significantly at index (priority 1) nesting beaches and many secondary beaches in the region	30+ years of work in Mexico (Laura Sarti, Conanp, Kutzari, Proyecto Laud), Costa Rica (Spotila, Paladino, Santidrian-Tomillo, The Leatherback Trust; SINAC), and ~20 years in Nicaragua (FFI)
Regardless of any ex situ actions, sustaining and enhancing in situ conservation actions on nesting beaches and in marine habitats are required to recover the EP leatherback population. Efforts to date have likely prevented extinction already	Laud OPO (2020, Scientific Reports) and Miller/CPSG models; numerous comments in the workshop sessions ;)
Fact (or something): We, the experts in EP leatherback biology and conservation, should establish and work to implement priority conservation actions	Just because rich people might like to chase the new/big/shiny/clout-giving things, or they are not attracted to the difficult/boring/long-term actions that we know are essential, does not mean that we should simply follow their interests (or lack thereof). It is our job to 'sell' what is best for conservation, given our expertise, not to follow money as justification for a set of actions
Social situation and governmental support on beaches and in artisanal fisheries remain receptive to conservation action.	
Turtle biology does not change.	

Assumptions	Why do we assume this?
100 to 200 sub adult or adult leatherbacks must be saved annually to achieve sufficient mortality reduction to cause a positive population trajectory	Rough estimates based on stable age distributions in Laud OPO (2020, Scientific Reports) and Miller/CPSG models; we do not know with certainty the total number of turtles caught (and killed) annually in the East Pacific, nor do we know the actual abundances of different age classes
That we have sufficient resources, political will, and capability to reduce bycatch to levels (25-40%) sufficient to ensure persistence of EP leatherbacks even beyond 15-30 years. Human population growth continues and demand for seafood and marine resources increases accordingly. Political will to invest resources in enforcement, monitoring, and vigilance is tenuous at best and governance (within territorial waters) is ephemeral. Outside of territorial waters, it is a free-for-all. If we fail to achieve the bycatch reduction objectives, we will lose EP leatherbacks.	As evidenced during the past 30 years of efforts directed at protecting EP/WP leatherbacks and other vulnerable marine species, we have limited understanding about the scope/scale of the bycatch problem and limited ability to respond at the scope and scale necessary to effectively curtail fisheries interactions. There are many noteworthy bycatch mitigation initiatives occurring across the EP region and worldwide, but these efforts pale in comparison to the scale of the challenge. Leatherbacks are threatened everywhere they travel (and they cover enormous distances), within EEZs (where enforcement and vigilance is limited and highly variable) and across the high seas, where no enforcement exists whatsoever. Illegal, unregulated, and unreported fisheries also likely interact with leatherbacks. RFMOs and national governments have been challenged to develop the regulations and policies necessary to effectively reduce interactions. As the PVA models indicate the trajectories are bleak and time is very limited to achieve the bycatch reduction goals necessary to stave off extirpation. This is particularly apparent for the Costa Rica nesting population but also very clear for the Mexican nesting population.

We assume that nearly all mortality of sub adults and adults is due to fisheries bycatch.	Responses to this point- Found 14 dead leatherback turtles destined for human consumption in Pisco (14°S) in Peru; Necropsies done on dead sub-adults that show evidence of drowning; The majority (90-95%?) of the sea turtle deaths are probably from bycatch, but perhaps a percentage are due to other causes, such as poisoning or due to plastics; At least In the Atlantic turtles also die from other causes such as consuming plastic bags etc. I don't know if this is the case in South America; Bubbles found in some of the five post-mortems we have carried out on fresh, dead turtles showed bubbles [within the respiratory tract] which was indicative of drowning; The majority of the turtle post-mortems that we have done are on sub-adults from 85-95cm, and- when fresh- you find bubbles which are signs of drowning, and so it is likely that the mortality was caused by incidental capture
Specific details on fisheries methods (nets, longlines, etc.) are not included in the PVA.	Responses to this point- In Chile, the most impactful fishing gear is the net; In Peru as well the major impact is due to the drift gill nets; Most of the turtles we have found show evidence of having died in nets rather than tan longlines; There are very few observers for the thousands and thousands of longline fishing boats out there. It is difficult to know how much of an impact they are having.

Knowledge gaps	How could we fill this gap?
Relative impact of different fishing gear on turtle mortality	Useful to compile very briefly known/estimated efficacy of bycatch reduction in different gear types? To give at least a very general idea of 'if this was done, this amount of reduction is possible?'
Like above, we do not know the true abundance and age/stage-structure of the EP leatherback population, so our population models likely oversimplify important processes	We only count nesting females (and their eggs and hatchlings) well enough to estimate trends and abundance in those life stages. We have very limited information about young juveniles, and only very little about putative 'sub adults'
The true nature and effects of underlying environmental drivers of vital life history traits (resource acquisition patterns, growth, age and size at maturity, transient probabilities, remigration intervals, reproductive output, etc.)	We know things like ENSO influence remigration probability, but there is a lot of unexplained variance. Also, there have apparently been long-term (turtle generation as well as geological time) fluctuations in EP leatherback (and other sea turtles) populations in the Eastern Pacific that appear to reflect long-term fluctuations in environmental conditions
The scope, scale, and impacts of other threats (e.g. plastic pollution, climate change) individually and cumulatively (e.g. in combination with bycatch) are unknown. For example, plastic pollution may be extinguishing entire cohorts of turtles, whose behavior/movements/aggregations at early life history stages remains entirely enigmatic. While we focus on the threats that are most evident, we may be missing other threats that are equally insidious. We are focusing entirely on two interventions (beach protection and bycatch mitigation but we may be missing other extinction drivers.	There are many recent articles on this theme - too exhaustive to provide here. A few informative ones, include Plastic Ingestion in Post-hatchling Sea Turtles: Assessing a Major Threat in Florida Near Shore Waters (Eastman et al. 2020); Plastic ingestion in oceanic-stage loggerhead sea turtles (*Caretta caretta*) off the North Atlantic subtropical gyre (Pham et al. 2017); Global Analysis of Anthropogenic Debris Ingestion by Sea Turtles (Schuyler et al. 2013); Plastic Debris in a Nesting Leatherback Turtle in French Guiana (Plot and Georges, 2010)
Cost and for how long this management should it be implemented.	Experimentation of mitigation measures in fishing fleets
Improving knowledge on post-release survival (from fishing)	Research about the potential grouping of Laud turtles

Improve knowledge of environmental variables influencing the distribution of leatherbacks	Economic value of the implementation of mitigation actions to evaluate the effect that it could have on fisheries process
Bycatch has not enough evaluations due to lack of watchers on boats and I do not know if we know the bycatch mortality data in international waters	More research on the use of shade cloth; Use the valuable information from necropsies of turtles to determine their main causes of death on the coastline independently of interaction by fisheries; Implementing bycatch monitoring in artisanal fleets
We do not know about the impact of climate change and food availability on turtle mortality	Spatial mapping between the distribution of their prey (*Chrysaora* and *Pyrosomas*) and the distribution of laud on spatial-temporal scales.

APPENDIX III CALCULATIONS FOR SCENARIO COSTINGS (APPROXIMATE)

Head-start – 6000 eggs

Headstart: 6000 Eggs	Model Year	Cost	# Released (3 months)	Cost/Release	(Sub)Adult Survival	# Age-12 (Adult Fem)	# Adult Females	Cost/Age-12
	1				0.75			
	2				0.75			
	3	$ 414,000.00	750	$ 552.00	0.75			
	4	$ 414,000.00	924	$ 448.05	0.75			
	5	$ 414,000.00	1116	$ 370.97	0.75			
	6	$ 414,000.00	1326	$ 312.22	0.755			
	7	$ 414,000.00	1554	$ 266.41	0.76			
	8	$ 414,000.00	1800	$ 230.00	0.765			
	9	$ 414,000.00	1800	$ 230.00	0.77			
	10	$ 414,000.00	1800	$ 230.00	0.775			
	11	$ 414,000.00	1800	$ 230.00	0.78			
	12	$ 414,000.00	1800	$ 230.00	0.785			
	13	$ 414,000.00	1800	$ 230.00	0.79			
	14	$ 414,000.00	1800	$ 230.00	0.795	2.961	2.487	$ 139,807.88
	15	$ 414,000.00	1800	$ 230.00	0.8	3.866	3.247	$ 107,097.15
	16	$ 414,000.00	1800	$ 230.00	0.8	4.915	4.128	$ 84,238.24
	17	$ 414,000.00	1800	$ 230.00	0.8	6.107	5.130	$ 67,795.58
	18	$ 414,000.00	1800	$ 230.00	0.8	7.435	6.246	$ 55,679.41
	19	$ 414,000.00	1800	$ 230.00	0.8	8.890	7.468	$ 46,567.71
	20	$ 414,000.00	1800	$ 230.00	0.8	9.118	7.659	$ 45,403.52
	21	$ 414,000.00	1800	$ 230.00	0.8	9.292	7.806	$ 44,552.20
	22	$ 414,000.00	1800	$ 230.00	0.8	9.410	7.904	$ 43,995.30
	23	$ 414,000.00	1800	$ 230.00	0.8	9.469	7.954	$ 43,720.33
	24	$ 414,000.00	1800	$ 230.00	0.8	9.469	7.954	$ 43,720.33
	25	$ 414,000.00	1800	$ 230.00	0.8	9.469	7.954	$ 43,720.33
	26	$ 414,000.00	1800	$ 230.00	0.8	9.469	7.954	$ 43,720.33
	27	$ 414,000.00	1800	$ 230.00	0.8	9.469	7.954	$ 43,720.33
	28				0.8	9.469	7.954	$ 43,720.33
	29	**$ 10,350,000.00**	**41670**	**$ 248.38**	0.8	9.469	7.954	$ 43,720.33
	30				0.8	9.469	7.954	$ 43,720.33
	31				0.8	9.469	7.954	$ 43,720.33
	32				0.8	9.469	7.954	$ 43,720.33
	33				0.8	9.469	7.954	$ 43,720.33
	34				0.8	9.469	7.954	$ 43,720.33
	35				0.8	9.469	7.954	$ 43,720.33
	36				0.8	9.469	7.954	$ 43,720.33
	37				0.8	9.469	7.954	$ 43,720.33
	38				0.8	9.469	7.954	$ 43,720.33
						213.503		**$ 48,477.06**

Egg Translocation A – 6000 eggs

Translocation-A: 6000 Eggs	Model Year	Cost	# Released (3 months)	Cost/Release	(Sub)Adult Survival	# Age-12 (Adult Fem)	# Adult Females	Cost/Age-12
	1				0.75			
	2				0.75			
	3	$ 119,540.00	5700	$ 20.97	0.75			
	4	$ 119,540.00	5700	$ 20.97	0.75			
	5	$ 119,540.00	5700	$ 20.97	0.75			
	6	$ 119,540.00	5700	$ 20.97	0.755			
	7	$ 119,540.00	5700	$ 20.97	0.76			
	8	$ 119,540.00	5700	$ 20.97	0.765			
	9	$ 119,540.00	5700	$ 20.97	0.77			
	10	$ 119,540.00	5700	$ 20.97	0.775			
	11	$ 119,540.00	5700	$ 20.97	0.78			
	12	$ 119,540.00	5700	$ 20.97	0.785			
	13	$ 119,540.00	5700	$ 20.97	0.79			
	14	$ 119,540.00	5700	$ 20.97	0.795	6.330	5.317	$ 18,883.69
	15	$ 119,540.00	5700	$ 20.97	0.8	6.708	5.634	$ 17,821.48
	16	$ 119,540.00	5700	$ 20.97	0.8	7.061	5.931	$ 16,930.41
	17	$ 119,540.00	5700	$ 20.97	0.8	7.384	6.202	$ 16,189.70
	18	$ 119,540.00	5700	$ 20.97	0.8	7.671	6.444	$ 15,582.59
	19	$ 119,540.00	5700	$ 20.97	0.8	7.919	6.652	$ 15,095.63
	20	$ 119,540.00	5700	$ 20.97	0.8	8.122	6.822	$ 14,718.24
	21	$ 119,540.00	5700	$ 20.97	0.8	8.277	6.953	$ 14,442.28
	22	$ 119,540.00	5700	$ 20.97	0.8	8.382	7.041	$ 14,261.75
	23	$ 119,540.00	5700	$ 20.97	0.8	8.435	7.085	$ 14,172.61
	24	$ 119,540.00	5700	$ 20.97	0.8	8.435	7.085	$ 14,172.61
	25	$ 119,540.00	5700	$ 20.97	0.8	8.435	7.085	$ 14,172.61
	26	$ 119,540.00	5700	$ 20.97	0.8	8.435	7.085	$ 14,172.61
	27	$ 119,540.00	5700	$ 20.97	0.8	8.435	7.085	$ 14,172.61
	28				0.8	8.435	7.085	$ 14,172.61
	29	**$ 2,988,500.00**	**142500**	**$ 20.97**	0.8	8.435	7.085	$ 14,172.61
	30				0.8	8.435	7.085	$ 14,172.61
	31				0.8	8.435	7.085	$ 14,172.61
	32				0.8	8.435	7.085	$ 14,172.61
	33				0.8	8.435	7.085	$ 14,172.61
	34				0.8	8.435	7.085	$ 14,172.61
	35				0.8	8.435	7.085	$ 14,172.61
	36				0.8	8.435	7.085	$ 14,172.61
	37				0.8	8.435	7.085	$ 14,172.61
	38				0.8	8.435	7.085	$ 14,172.61
						202.807		**$ 14,735.71**

Egg Translocation B – 6000 eggs

Translocation-B: 6000 Eggs	Model Year	Cost	# Released (3 months)	Cost/Release	(Sub)Adult Survival	# Age-12 (Adult Fem)	# Adult Females	Cost/Age-12
	1				0.75			
	2				0.75			
	3	$ 165,600.00	2850	$ 58.11	0.75			
	4	$ 165,600.00	3135	$ 52.82	0.75			
	5	$ 165,600.00	3420	$ 48.42	0.75			
	6	$ 165,600.00	3705	$ 44.70	0.755			
	7	$ 165,600.00	3990	$ 41.50	0.76			
	8	$ 165,600.00	4275	$ 38.74	0.765			
	9	$ 165,600.00	4275	$ 38.74	0.77			
	10	$ 165,600.00	4275	$ 38.74	0.775			
	11	$ 165,600.00	4275	$ 38.74	0.78			
	12	$ 165,600.00	4275	$ 38.74	0.785			
	13	$ 165,600.00	4275	$ 38.74	0.79			
	14	$ 165,600.00	4275	$ 38.74	0.795	4.522	3.798	$ 36,623.68
	15	$ 165,600.00	4275	$ 38.74	0.8	5.270	4.427	$ 31,421.46
	16	$ 165,600.00	4275	$ 38.74	0.8	6.052	5.084	$ 27,362.85
	17	$ 165,600.00	4275	$ 38.74	0.8	6.856	5.759	$ 24,152.98
	18	$ 165,600.00	4275	$ 38.74	0.8	7.671	6.444	$ 21,586.72
	19	$ 165,600.00	4275	$ 38.74	0.8	8.484	7.127	$ 19,518.00
	20	$ 165,600.00	4275	$ 38.74	0.8	8.702	7.310	$ 19,030.05
	21	$ 165,600.00	4275	$ 38.74	0.8	8.868	7.449	$ 18,673.23
	22	$ 165,600.00	4275	$ 38.74	0.8	8.981	7.544	$ 18,439.82
	23	$ 165,600.00	4275	$ 38.74	0.8	9.037	7.591	$ 18,324.57
	24	$ 165,600.00	4275	$ 38.74	0.8	9.037	7.591	$ 18,324.57
	25	$ 165,600.00	4275	$ 38.74	0.8	9.037	7.591	$ 18,324.57
	26	$ 165,600.00	4275	$ 38.74	0.8	9.037	7.591	$ 18,324.57
	27	$ 165,600.00	4275	$ 38.74	0.8	9.037	7.591	$ 18,324.57
	28				0.8	9.037	7.591	$ 18,324.57
	29	**$ 4,140,000.00**	**102600**	**$ 40.35**	0.8	9.037	7.591	$ 18,324.57
	30				0.8	9.037	7.591	$ 18,324.57
	31				0.8	9.037	7.591	$ 18,324.57
	32				0.8	9.037	7.591	$ 18,324.57
	33				0.8	9.037	7.591	$ 18,324.57
	34				0.8	9.037	7.591	$ 18,324.57
	35				0.8	9.037	7.591	$ 18,324.57
	36				0.8	9.037	7.591	$ 18,324.57
	37				0.8	9.037	7.591	$ 18,324.57
	38				0.8	9.037	7.591	$ 18,324.57
						210.000		**$ 19,714.31**

Egg Translocation C – 6000 eggs

Translocation-C: 6000 Eggs	Model Year	Cost	# Released (3 months)	Cost/Release	(Sub)Adult Survival	# Age-12 (Adult Fem)	# Adult Females	Cost/Age-12
	1				0.75			
	2				0.75			
	3	$ 424,000.00	713	$ 594.67	0.75			
	4	$ 424,000.00	878	$ 482.92	0.75			
	5	$ 424,000.00	1060	$ 400.00	0.75			
	6	$ 424,000.00	1260	$ 336.51	0.755			
	7	$ 424,000.00	1476	$ 287.26	0.76			
	8	$ 424,000.00	1710	$ 247.95	0.765			
	9	$ 424,000.00	1710	$ 247.95	0.77			
	10	$ 424,000.00	1710	$ 247.95	0.775			
	11	$ 424,000.00	1710	$ 247.95	0.78			
	12	$ 424,000.00	1710	$ 247.95	0.785			
	13	$ 424,000.00	1710	$ 247.95	0.79			
	14	$ 424,000.00	1710	$ 247.95	0.795	2.815	2.365	$ 150,615.23
	15	$ 424,000.00	1710	$ 247.95	0.8	3.673	3.085	$ 115,430.58
	16	$ 424,000.00	1710	$ 247.95	0.8	4.668	3.921	$ 90,830.80
	17	$ 424,000.00	1710	$ 247.95	0.8	5.803	4.874	$ 73,070.13
	18	$ 424,000.00	1710	$ 247.95	0.8	7.062	5.932	$ 60,037.81
	19	$ 424,000.00	1710	$ 247.95	0.8	8.446	7.094	$ 50,202.67
	20	$ 424,000.00	1710	$ 247.95	0.8	8.662	7.276	$ 48,947.60
	21	$ 424,000.00	1710	$ 247.95	0.8	8.828	7.415	$ 48,029.83
	22	$ 424,000.00	1710	$ 247.95	0.8	8.940	7.509	$ 47,429.46
	23	$ 424,000.00	1710	$ 247.95	0.8	8.996	7.556	$ 47,133.03
	24	$ 424,000.00	1710	$ 247.95	0.8	8.996	7.556	$ 47,133.03
	25	$ 424,000.00	1710	$ 247.95	0.8	8.996	7.556	$ 47,133.03
	26	$ 424,000.00	1710	$ 247.95	0.8	8.996	7.556	$ 47,133.03
	27	$ 424,000.00	1710	$ 247.95	0.8	8.996	7.556	$ 47,133.03
	28				0.8	8.996	7.556	$ 47,133.03
	29	**$ 10,600,000.00**	**39587**	**$ 267.76**	0.8	8.996	7.556	$ 47,133.03
	30				0.8	8.996	7.556	$ 47,133.03
	31				0.8	8.996	7.556	$ 47,133.03
	32				0.8	8.996	7.556	$ 47,133.03
	33				0.8	8.996	7.556	$ 47,133.03
	34				0.8	8.996	7.556	$ 47,133.03
	35				0.8	8.996	7.556	$ 47,133.03
	36				0.8	8.996	7.556	$ 47,133.03
	37				0.8	8.996	7.556	$ 47,133.03
	38				0.8	8.996	7.556	$ 47,133.03
						202.830		**$ 52,260.57**

All calculations in the above tables assume:

- *Ex situ* effort = 6000 eggs.
- *Ex situ* management location = Mexico (just for demonstration purposes).
- For head-starting, a 25% increase in post-release survival to Age-1 compared to turtles hatched in natural nests.
- The number of individuals released (Column E) considers, where appropriate, the gradual improvement in husbandry over time (beginning in year 3 and continuing to improve over 5 years), reflected in increased hatching rate (0.5 to 0.75) and post-hatch survival to three months (0.25 to 0.4).
- Similarly, the calculation of Age-12 individuals (chosen as this corresponds to the age of adulthood in females) considers the gradual improvement in subadult and adult survival over time, beginning in year 5 and continuing to improve over a 10-year period.
- The number of Age-12 individuals produced each year from released turtles (column H) is estimated by starting with the cohort of released individuals 12 years prior, and then applying the appropriate annual survivorship values in column G.

  For example:

  - The first group of 750 head-started turtles is released as 3-month-olds in model year 3 (Headstart tab, cell E5).
  - Survival to Age-1 is 1.25*(0.794^9). This accounts for the 25% increase in post-release survival, which is calculated over a 9-month period since the turtles are released at 3 months old.
  - Survival to Age-2 and survival to Age-3 is 0.5 each year, meaning the total survival to Age-3 is 0.25.
  - The first year of subadult (Age-3+) survival for this release cohort is model year 6 since they were first released in model year 3. Therefore, the total survival from Age-3 to Age-12 is obtained by multiplying the values in cells G8-G16. This is seen in the formula used in cell H16 to calculate the total number of new Age-12 turtles expected to be counted from the original release cohort. So, in the head-start example, a total of 2.96 Age-12 turtles is expected from the initial cohort of 750 turtles released. Because of improvements in both *ex situ* husbandry and in situ survival of older turtles through bycatch mitigation, that number of Age-12 animals is expected to increase to 9.5 turtles at model year 23.

  The same general logic carries through each of the different ex situ options, with different survival values, etc. that are appropriate to a specific strategy.

APPENDIX IV ITEMS INCLUDED WITHIN COST CALCULATIONS FOR TABLE 4

Set-up costs of head-starting facility:

- Building or enclosure for housing tanks and turtles
- Air-conditioning units for facility
- Solar panels for electricity generation (including installation and battery system)
- Tanks for housing turtles
- Sump tanks
  - Ocean intake pump and piping/ Pumps for rearing tanks
  - PVC piping
- Temperature control systems (heat pumps / evaporative coolers)
- Drainage systems
- Bio-Filtration systems for tanks
- Full-spectrum lighting
- Electricity
- Oxygen, pH, and temperature probes)
- Fishing line for tethering turtles
- Velcro for tethering turtles
- Veterinary glue for tethering turtles
- Pool scoops for collecting animals from tanks
- Plastic sheeting for dividing tanks
- Egg Incubators (only required if incubating eggs at rearing facility)
- Air-conditioning unit for egg incubation room
- Temperature probes for incubators
- Temperature sensor units

Annual maintenance costs of head-starting facility:

- Chemicals / antibiotics / disinfectants
- Food
- Plastic gloves
- Staffing / Labor Costs (variation w/ experience of employee and location of facility)
- Facility Director / Lead Scientist
- Facility technicians

Egg collection and transportation of translocated eggs:

- Plastic gloves (vinyl and nitrile)
- Reusable vacuum-sealed plastic bags for egg collection (where appropriate to reuse)
- Air & ground freight
- Cooler boxes for egg transport
- Buckets for hatchling transport
- Plastic box containers for hatchling transport

Set-up & annual maintenance costs of artificial incubation facility:

- Hovabator Incubators
- Air-conditioning unit for egg incubation room
- Temperature probes for incubators (including replacement costs)
- Temperature sensor units
- Solar panels for electricity generation (including installation and battery system)
- Building / Room for Incubation of Eggs
- Plastic gloves
- Facility Director / Lead Scientist
- Facility technicians

Genetic fingerprinting costs:

- Development of primers for fingerprinting
- Cost of fingerprinting each individual (hatchlings and nesting females)

Turtle release costs:

- Boat hire (25 turtles released per day)
- Satellite tags for subsample of released animals
- Buckets for housing turtles on boat
- Coolers

APPENDIX V RESPONSES TO INTERIM WORKSHOP SURVEY

Q1 To what extent would you agree with the following statements so far?/ ¿En qué medida estaría de acuerdo con las siguientes afirmaciones hasta ahora?

Answered: 17 Skipped: 0

	1. I DON'T AGREE AT ALL/ NO ESTOY DE ACUERDO EN ABSOLUTO	2.	3. I AGREE/ ESTOY DE ACUERDO	4.	5. I STRONGLY AGREE/ ESTOY TOTALMENTE DE ACUERDO	I'M NOT SURE/ NO ESTOY SEGURO	TOTAL
Based on what I have heard in the workshop so far, I see no value in undertaking ex situ studies to answer some of the related assumptions and knowledge gaps/Según lo que he escuchado en el taller hasta ahora, no veo ningún valor en realizar estudios ex situ para responder a algunas de las suposiciones relacionadas y lagunas de conocimiento.	47.06% 8	29.41% 5	11.76% 2	5.88% 1	5.88% 1	0.00% 0	17
I think that before ex situ management is undertaken, applied research is required to answer key assumptions and knowledge gaps/ Creo que antes de emprender el manejo ex situ, se requiere investigación aplicada para responder supuestos clave y brechas de conocimiento	11.76% 2	11.76% 2	23.53% 4	0.00% 0	52.94% 9	0.00% 0	17
We should start ex situ management now and learn through doing/Deberíamos comenzar la gestión ex situ ahora y aprender haciendo	47.06% 8	11.76% 2	0.00% 0	5.88% 1	17.65% 3	17.65% 3	17
I do think that someone should begin ex situ management trials, though this is not something that I would feel able to contribute to/ Creo que alguien debería comenzar los ensayos de manejo ex situ, aunque esto no es algo a lo que me sienta capaz de contribuir.	25.00% 4	18.75% 3	25.00% 4	6.25% 1	18.75% 3	6.25% 1	16

#	USE THIS SPACE TO PROVIDE AN EXPLANATION FOR ANY OF YOUR RESPONSES.../ UTILICE ESTE ESPACIO PARA PROPORCIONAR UNA EXPLICACIÓN DE CUALQUIERA DE SUS RESPUESTAS ...	DATE
1	I think it makes sense to begin ex situ with leatherbacks on a small scale, using doomed eggs at first so that basic husbandry techniques can be developed. Once success at that has been achieved, it would make sense to scale up. We could begin by using doomed eggs and then scale up by translocating eggs from other locations in the same ocean basin and preferably from the same general region (eastern Pacific). I am concerned about relying entirely on reducing bycatch, as that has been tried for some years and has not yet been fully successful. For this reason, it makes sense to have an additional plan in place to try to help the population.	2/4/2021 9:30 PM
2	Me parece que el manejo Ex situ debe ser la ULTIMA opción para poder proteger a la POBLACIÓN (genetic stock). Y asegurarse de que el Headstarting no solo sea exitoso asegurando que las tortugas regresen a la playa, también de que éstas no puedan llevar enfermedades adquiridas en cautiverio a las silvestres.	2/4/2021 9:27 PM
3	I don't think that the expected value of ex situ management (i.e., PVA assumptions) has been adequately discussed in this workshop, nor have specific strategies (e.g., donor populations) been considered. My answers reflect the following: For ex situ management to have any benefit, it requires assumptions of survival that are likely fanciful given the species and scenarios pondered during this meeting (inter-oceanic translocation). I do not expect significant areas of uncertainty to be addressed by studies due to infeasibility.	2/4/2021 8:13 PM
4	Estoy pensando el exito que esto puede generar en la poblacion asi como las implicaciones economicas, de realizarce investigaciones por cuanto tiempo y hasta cuando se podra ver el resultado, esas muchas de las dudas que tengo, por que con playa pasa que hay proyectos con mas de 30 anos liberando tortuguitas y pues aun es muy bajo la tasa de retorno a las playas de anidacion.	2/4/2021 7:59 PM
5	I think any new/additional funding and research should go toward supporting the highest priority conservation measures, which are entirely in situ, and mainly dealing with fisheries bycatch reduction. Ex situ benefits are theoretical, and based on best-case scenario assumptions that are unlikely to be met in reality. Research studies to try and fill knowledge gaps will largely be just that: research exercises with minimal real-world application.	2/4/2021 7:28 PM
6	Most of the arguments I've heard against pursuing ex situ options seem based on the lack of knowledge - which should not be a death knell to pursuing new options. The only real data in hand indicate that what is currently happening is not working.	2/4/2021 7:16 PM
7	Regarding the last question, I think that someone should begin ex situ management trials. This is something that I would also feel comfortable contributing too.	2/4/2021 6:08 PM
8	Me parece confusa la pregunta porque en sí ya es una negación: Según lo que he escuchado en el taller hasta ahora, no veo ningún valor en realizar estudios ex situ para responder a algunas de las suposiciones relacionadas y lagunas de conocimiento. Yo si veo valor en realizar los estudios Ex situ . en esta otra pregunta también tengo duda: Creo que alguien debería comenzar los ensayos de manejo ex situ, aunque esto no es algo a lo que me sienta capaz de contribuir. Yo creo que soy capaz de contribuir y sino es posible en nuestras instalaciones poder brindar nuestras experiencias .	2/4/2021 5:57 PM
9	Developing a list of key research questions would be a great product from this workshop.	2/4/2021 5:38 PM
10	Existe suficiente incertidumbre en el tema de medidas ex-situ como para pensar en hacer experimentos muy puntuales que permitan generar información necesaria sobre medidas de manejo, estructura poblacional y genética, y estabilidad de la población	2/4/2021 5:29 PM
11	Research to answer key assumptions and knowledge gaps is valuable, under specific conditions, but I strongly disagree with ex-situ management at this point, where there are other very clear priorities. Ex-situ management should be the very, very last resource, and I don't think the Eastern Pacific leatherback is there yet.	2/4/2021 5:16 PM

Q2 Would you be interested in collaborating with others to plan ex situ management studies to address key assumptions or knowledge gaps?/ ¿Estaría interesado en colaborar con otros para planificar estudios de manejo ex situ para abordar supuestos clave o brechas de conocimiento?

ANSWER CHOICES	RESPONSES	
Yes/ Si	58.82%	10
No	29.41%	5
Im not sure/ no estoy seguro	17.65%	3
If 'Yes' please go to question 3; If 'No' please go to question 4/ Si la respuesta es "Sí", pase a la pregunta 3; Si la respuesta es "No", pase a la pregunta 4.	0.00%	0
Total Respondents: 17		

Q3 Which research studies would you be interested to collaborate on?/ ¿En qué estudios de investigación le interesaría colaborar?

Answered: 11 Skipped: 6

#	RESPONSES	DATE
1	I could help with navigation studies, if there is a way to do them. But it would be challenging	2/4/2021 9:30 PM
2	Translocation and headstarting trials. Navigation studies.	2/4/2021 9:21 PM
3	egg relocation, hatchling husbandry, estimates of survival, hatchling tracking	2/4/2021 8:48 PM
4	Any	2/4/2021 7:41 PM
5	those that explore measures to improve hatching success and hatchling production	2/4/2021 7:28 PM
6	I am interested to collaborate on any aspect of this work. Both questions that can be answered via PVA modeling: genetic implications, impact on source population, post-headstarting survival, etc., and any pilot "doomed" egg research studies with headstarting and/or translocation.	2/4/2021 7:27 PM
7	Could potentially assist with husbandry studies.	2/4/2021 7:16 PM
8	Research directed at understanding dispersal, navigation, genetic implications, optimizing translocation, incubation, and husbandry, economic and social studies to to raise awareness, exploration of linkage/synergies with in-situ efforts to maximize engagement, promote habitat conservation and bycatch mitigation measures, and ensure that ex situ conservation efforts can effectively complement and strengthen ongoing in situ conservation work.	2/4/2021 6:08 PM
9	Movimientos de migración, uso de habitat y telemetria satelital	2/4/2021 6:02 PM
10	En manejo en cautiverio para crecimiento y posterior liberación de crías. Si me es posible contribuir en otro con seguridad estaré dispuesta	2/4/2021 5:57 PM
11	Moderación de escenarios ecológicos y poblacionales (modelación)	2/4/2021 5:29 PM

Q4 What research studies would you recommend as priorities to inform ex situ management decisions?/ ¿Qué estudios de investigación recomendaría como prioridades para informar las decisiones de manejo ex situ?

Answered: 14 Skipped: 3

#	WE SHOULD STUDY/NOSOTROS DEBERIAMOS ESTUDIAR...	DATE
1	feasibility of raising leatherbacks in captivity	2/4/2021 9:30 PM
2	en una población más estable que la del Pacífico Oriental.	2/4/2021 9:27 PM
3	Leatherback navigational behaviour	2/4/2021 9:21 PM
4	imprinting and geonavigation	2/4/2021 8:48 PM
5	poblacion de origen	2/4/2021 7:59 PM
6	Increasing hatching success	2/4/2021 7:41 PM
7	egg handling and incubation techniques to increase hatching success	2/4/2021 7:28 PM
8	The impact on source populations.	2/4/2021 7:27 PM
9	egg viability	2/4/2021 7:16 PM
10	Navigation - learned migration, role of currents, inherent navigation/orientation	2/4/2021 6:08 PM
11	Ecología trofica	2/4/2021 6:02 PM
12	Try to mimic Lohmann's loggerhead navigation studies with leatherbacks (assuming the husbandry challenges can get worked out)	2/4/2021 5:38 PM
13	Manejo en cautiverio	2/4/2021 5:29 PM
14	possible impact of translocations over ocean basins for the genetic population structure of the species	2/4/2021 5:16 PM

#	WE SHOULD STUDY/NOSOTROS DEBERIAMOS ESTUDIAR...	DATE
1	Monitoreo y marcaje de machos en zonas de alimentacion (ya que estos no los logramos ver en playa)	2/4/2021 7:59 PM
2	Social and economic implications and measures to increase political engagement, raise awareness abut conservation need, engage community stakeholders, governments, and the broader public in the urgency to identify and implement solutions that will ensure recovery of EP leatherbacks.	2/4/2021 6:08 PM
3	Incentivos a pescadores	2/4/2021 5:29 PM

#	WE SHOULD STUDY/NOSOTROS DEBERIAMOS ESTUDIAR...	DATE
1	ideally we should study navigation but it would be very difficult	2/4/2021 9:30 PM
2	La eficiencia de la sobrevivencia y la impronta de tortugas traslocadas.	2/4/2021 9:27 PM
3	Best-practice egg transport	2/4/2021 9:21 PM
4	husbandry	2/4/2021 8:48 PM
5	genetica de los individuos de este manejo	2/4/2021 7:59 PM
6	How to grow posthatchling leatherbacks in an open ocean system such as is used in aquaculture operations	2/4/2021 7:41 PM
7	the logistics of the translocation and headstarting processes.	2/4/2021 7:27 PM
8	captive diet	2/4/2021 7:16 PM
9	Early stage post-release survival, methods to monitor success over long-term (e.g. DNA fingerprinting and linking bycaught juveniles/subadults to source)	2/4/2021 6:08 PM
10	Estudios de salud en general	2/4/2021 6:02 PM
11	incubation (hatching) success of leatherbacks from a population that is a candidate for translocation by first conducting manipulative studies near their true natal beaches to see if they can survive in a modified incubation setting similar to where they would be translocated to. (mimicking seasonal temperatures and humidity at the ex situ site)	2/4/2021 5:38 PM
12	Estructura genetica y poblacional	2/4/2021 5:29 PM
13	possible diseases that would affect captive-rearing of leatherbacks in the Pacific	2/4/2021 5:16 PM

#	WE SHOULD STUDY/NOSOTROS DEBERIAMOS ESTUDIAR...	DATE
1	Asegurar que las tortugas con headstarting no sean portadoras de enfermedades contagiosas a otras tortugas.	2/4/2021 9:27 PM
2	hatching survival and fitness in captivity	2/4/2021 9:21 PM
3	hatchling survival rates	2/4/2021 8:48 PM
4	La ruta migratoria y la pesca incidental para asegurar sobrevivencia	2/4/2021 7:59 PM
5	Where, how and when to release posthatchling leatherbacks	2/4/2021 7:41 PM
6	post release survivability	2/4/2021 7:16 PM
7	Husbandry advances -- diet, pathology, how to increase success and improve survival	2/4/2021 6:08 PM
8	ways to maximize survivorship in captivity	2/4/2021 5:38 PM
9	Efectos anuales del bycatch a nivel regional	2/4/2021 5:29 PM

#	WE SHOULD STUDY/NOSOTROS DEBERIAMOS ESTUDIAR...	DATE
1	hatching survival (wild & head-started individuals)	2/4/2021 9:21 PM
2	improving hatching success	2/4/2021 8:48 PM
3	Marcaje para determinar tasa de retorno a playas de anidacion	2/4/2021 7:59 PM
4	Behavior and performance of transplanted eggs/hatchlings from one beach to another	2/4/2021 7:41 PM
5	PVAs for source populations, genetic implications of translocations	2/4/2021 6:08 PM
6	Modificaciones de artes de pesca	2/4/2021 5:29 PM

Q5 Please add here any other information that you think would help ensure the workshop results in the development of one or more, informed, recommendations/ Agregue aquí cualquier otra información que crea que ayudaría a garantizar que el taller dé como resultado el desarrollo de una o más recomendaciones informadas.

Answered: 8 Skipped: 9

#	RESPONSES	DATE
1	There were a lot of lessons learned during Kemp's ridley headstart program and these ultimately improved the program and process over the years it was operating. A lessons learned/best practice document has never been developed to my knowledge but would be useful for leatherbacks should ex situ conservation include headstarting	2/4/2021 7:41 PM
2	The 'recommendations' are still in a theoretical world. While I can theoretically imagine that ex situ measures could provide unequivocal population benefits, I have not seen/heard evidence of such a program actually providing demonstrable population benefits for sea turtle populations, and certainly not for leatherbacks, which are so different. The model results we've seen show marginal benefits, under best-case scenario assumptions, and even those scenarios are unrealistic given current realities. As you've heard repeatedly in these workshops, ex situ still seems very theoretical, with little clarity on HOW they could be done, with limited benefits and a lot of risks. Throughout the workshops, the 'strongest' and most consistent arguments in favor of doing ex situ measures have been some form of 'nothing is working, we have to try something before the population goes extinct.' I agree that we need to do more and better, but I disagree with the conclusion that ex situ is what needs to be tried. In my view, ex situ is not, nor will it ever be, the answer. In contrast to uncertainties related to the in situ conservation approaches, uncertainties and unknowns related to the ex situ conservation approaches might not be answered clearly or ever. This means that pursuing such measures will require leaps of faith that could have significant negative consequences (e.g., impacts on source populations, siphoning resources from other conservation activities for EP leatherbacks and/or other species, turtles that lack the ability to navigate properly, genetic mixing that is not beneficial or biologically appropriate)--beyond whether such measures would actually help EP leatherbacks. Put simply, ex situ measures--while attractive and theoretically beneficial to some species--are not the right conservation tools for leatherbacks, and probably not for any sea turtles. For these reasons, based on what we know now, I do not support pursuing ex situ measures. I could potentially see benefit of folks wanting to pursue research projects to fill knowledge gaps or improve assumptions identified by this process. But those would be primarily academic exercises that are not high priorities for EP leatherback conservation.	2/4/2021 7:28 PM
3	While not specific to the ex situ piece, it seems quantifying the success of any action is dependent of population survey methods haven't changed or evolved in a long time. Surely there are opportunities with technology to estimate relative abundances of free-ranging animals rather than just nesting females.	2/4/2021 7:16 PM
4	I think that interested workshop participants and the workshop organizers could share/distribute summarized draft versions of one or more final recommendations to participants following the meetings. Participants could be asked to provide edits, input, and this information would be captured within final workshop reports/outputs.	2/4/2021 6:08 PM
5	Existen experiencias, antecedentes de trabajo dentro de los participantes del taller que seguro son de utilidad para poder realizar un buen proyecto	2/4/2021 5:57 PM
6	At this stage the only thing i think i could support is a statement from the group stating that while the modeling shows the potential for ex-situ solutions in the abstract, and recognizing the urgency for finding solutions for the onogoing population decline of the EP leathrback, that there remain serious concerns and questions about the real-world applicability and effectiveness of ex-situ options and that any future work that does undertake any such research should take into account the concerns expressed by the group and seek to resolve those priority research and conservation concerns that have been raised before undertaking more widespread implementation.	2/4/2021 5:55 PM

7	Lets develop a flow chart, or sequential list, of what the key things are that would need to happen for ex situ to be viable, as well as what the challenges are associated with each of these. Also for each item, explicitly talk about risk. For some elements risk may be acceptable, whereas with others it may not. In these latter situations, I think it would be great for the group to discuss how we might mitigate this risk to get it to an acceptable level. For example, one of the risks may be concern about a mismatch of the inherited navigational abilities of leatherbacks with what their new environment presents. In such a case we can perhaps mitigate concerns about this risk by conducting captive trials as per Lohmann's prior work on loggerheads. Similarly, lets say the group feels very uncomfortable about where the eggs would come from. We can mitigate this concern by providing a recommendation / acknowledgement that eggs will only come from a stable or increasing population, or perhaps that eggs will only come from doomed nests. These are just examples. Finally, regarding husbandry, although we haven't talked about it too much yet, I think we all acknowledge the challenges of raising leatherbacks. In a sense this potential low survivorship is a risk, and in such a case maybe we develop a recommendation that focuses on developing more effective husbandry practices tailored specifically to leatherbacks (e.g. raised in infinity tanks, or with mini backpacks: full disclosure I know nothing about raising leatherbacks!)	2/4/2021 5:38 PM
8	Incluir todos los comentarios realizados por los miembros de la Red Laúd OPO	2/4/2021 5:29 PM