

A Population Viability Analysis of the
Bowmouth Guitarfish (*Rhina ancylostomus*):
Evaluating Release Strategies to Improve Wild Population Persistence



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and

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Summary

A workshop was held at Shedd Aquarium in Chicago, IL (USA) in 2023 to evaluate how a fledgling ex situ (aquarium) population of the Critically Endangered bowmouth guitarfish (*Rhina ancylostomus*) could most effectively support recovery of the species in its native range. Among the many decisions that emerged from this workshop was the recommendation to conduct a population viability analysis (PVA) to help outline a plan for releasing aquarium-born individuals into the wild in support of wild population recovery. This report presents the participatory process of developing the PVA, the results of the analysis, and the implications for release program planning.

The PVA was constructed using a stochastic simulation software package called Vortex. This software is well-suited for simulating the demographic dynamics of both in situ (wild) and ex situ (aquarium) populations, explicitly considering age- and sex-specific rates of reproduction and survival that determine long-term population growth rates. Moreover, Vortex has detailed modules that allow the user to construct complex translocation events defined by the number of individuals collected from a source (aquarium) population, the age and sex of the release cohort, and the duration and time interval of the releases. Because Vortex is an individual-based model, the genetic relationships among individual guitarfish can be used to simulate inbreeding depression and loss of population-level genetic variation through genetic drift.

A PVA Model Development Team met across multiple online sessions during January – April 2025 to create a consensus model input dataset. Preliminary simulation modeling results were presented and discussed at a subsequent in-person workshop held in May 2025 at Singapore Oceanarium. A key feature of the input dataset is a full studbook file describing the global aquarium population of bowmouth guitarfish whose genetic ancestry could be traced to a specific geographic area in southeast Asia. This area has been identified as the priority region in which a set of candidate release sites will soon be chosen. In the absence of a specific identified release site, the analysis adopts a more conservative approach by assuming a generic wild release site within the priority area but where bowmouth guitarfish are effectively absent, i.e., the initial population abundance is zero. This approach allows for a more explicit investigation of the release efforts in the aquarium population that would be required to promote future wild population growth and stability.

Another key feature of the PVA model is the separation of the global aquarium population holding bowmouth guitarfish of the proper geo-genetic ancestry into three regional populations: Asia, Europe and United States. This separation is considered realistic given the technical and logistical constraints that currently prohibit long-distance transport of larger individuals (i.e., typically older than pups) among regional aquaria populations. Because of its proximity to the priority release region, the Asia regional aquaria population is the source of individuals collected for release. Pups (animals just under one year of age) are collected from the regional aquaria population for release to the designated release site. Importantly, the model assumes that a “coalescence” event can take place within the next decade after the elimination of technical impediments to collecting and successfully transferring gametes (eggs and sperm). As a result of this event, the global aquaria can be effectively managed as a single breeding population, and adult females in the Asia region can potentially show improved reproductive success through mating with a wider array of unrelated individuals.

The model scenarios in this PVA – nearly 120 in total – are defined by unique combinations of broad ecological conditions in the release site and the specific details of the release effort:

- Wild population growth rate: Either High (long-term growth rate $\lambda = 1.08$) or Low (long-term growth rate $\lambda = 1.04$), representing the outcome of broad ecological characteristics of the release site such as habitat quality, prey availability, extent of anthropogenic mortality, etc. Overall, candidate release sites are assumed to benefit from at least moderate levels of active protection

from fishing and other detrimental human activities, thereby promoting conditions favorable for bowmouth guitarfish populations. Additionally, selected models include the impact of an El Niño climatic event that occasionally reduces rates of reproduction and survival and, by extension, the baseline population growth rates.

- Release program details: Varying levels of pup release intensity (25%, 50% or 75% of the annual pup production across the Asia regional aquaria population), release duration (10, 15 or 20 years) and release interval (annually, every other year, or every three years). The release mechanics simulated in the PVA include a realistic estimate of post-release survival that is expected to increase over time as managers improve their methods of pup collection, holding, transport and release.

Vortex features stochastic simulation mechanics, where replicate runs of the same model will produce a different result because of annual environment-based variability in the expected rates of age-specific reproduction and survival of individuals in a population. As a result, each model scenario is replicated 1000 times as it projects population performance forward in time (50 years). Key model output metrics for each scenario include the probability of wild population persistence and the mean adult population abundance at the end of the simulation. For the aquaria populations, an additional output metric of interest is the amount of gene diversity retained in the population through time, which is an important measure of genetic health of the population.

The following report presents a detailed graphical summary of the results across most of the scenarios comprising this analysis. In summary, important results from the analysis include the following observations:

- Demographic sensitivity analysis methods indicate that the outcome of a given model scenario is highly sensitive to the subadult (Age-1 to Age-5) mortality rate. This outcome can be explained by the relatively large number of individuals in this development cohort, as well as the comparatively long residency of an individual in this cohort. As a result, a specific proportional change in this annual survival rate typically leads to a greater change in population growth rate compared to an equivalent proportional change in another demographic parameter.
- The underlying population demographic profiles are significant factors influencing both the likelihood of population and the adult abundance of persisting populations. While persistence probability across the release scenarios is certainly reduced under the Low Growth profile, the impact of this reduced growth is considerably more evident when evaluating the associated abundance of adults among populations that persist for 50 years.
- As defined in this analysis, the El Niño climate event has a considerable impact on release population performance, particularly under the Low Growth demographic profile. The additional impact on adult abundance of persisting populations is pronounced under both population demographic profiles.
- The specific parameters governing the release program details appear to have a complex impact on the probability of facilitating population persistence across alternative population demographic profiles. For example, selecting a low proportion of aquarium-bred pups for release leads to a proportionally lower probability of population persistence in nearly all combinations of release program duration and release interval. The impact is most pronounced when the release program is short (e.g., 10 years) and the release interval is long (e.g., 3 years).
- The impacts of release program intensity, duration and interval on adult abundance among persisting populations are significant. A release program duration of 10 years results in a proportionally lower adult abundance than programs of longer duration, especially (and not

surprisingly) when a larger proportion of pups is selected from the aquarium population for release.

- Implementing a release program at a site with an existing bowmouth guitarfish population, even when that population is assumed to be quite small, can significantly increase the prospects for continued wild population viability. A more precise definition of this relationship is highly dependent on the nature of the existing wild population – its abundance, age-sex structure, expected reproductive success, etc. Overall, however, the presence of at least some adults in the wild release site facilitates more immediate production of offspring compared to a release site with no adults at the onset of the simulation.
- Failure to implement the global coalescence of the regional aquaria populations would result in the Asia regional population shouldering most if not all the responsibility for producing pups for release to a given wild release site. Simulations indicate that the desired number of pups could be produced across the full array of existing aquaria; however, the relatively small abundance of adults across this regional population would result in a rather high rate of gene diversity loss through time, ultimately dropping below the threshold level often used to define population genetic viability (e.g., 90% gene diversity retention over 50 years).

If long-term success of a bowmouth guitarfish release program were defined as (1) probability of wild population persistence at 50 years ≥ 0.9 , and (2) wild population-level gene diversity retention $\geq 90\%$ at 50 years, the release program characteristics should include:

- Collect at least 50% of the pups produced from the regional aquaria population in the year of release.
- Conduct pup releases at least every other year for a minimum of 15 years (i.e., eight total release events), with annual releases recommended if using both demographic and genetic criteria for population success.
- Mean annual growth rate of the wild population over the course of the 50-year program should be no less than 5% (i.e., $\lambda \geq 1.05$).
- Ideally, ex situ management efforts should strive for at least some coalescence of regional aquaria populations in order to facilitate more effective reproductive output and enhanced rates of gene diversity retention.

A standing population of bowmouth guitarfish in the chosen release site can significantly enhance short-term growth potential in the wild population; consequently, key characteristics of the release program as outlined above could be relaxed to achieve program success. The degree to which release intensity can be modified depends on the demographic characteristics of the existing population at that site.

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Introduction

In November 2023, Shedd Aquarium in Chicago, IL (USA) hosted an Ex Situ Conservation Assessment (ECA) workshop to evaluate how a fledgling ex situ (aquarium) population of the bowmouth guitarfish (*Rhina ancylostomus*), listed as Critically Endangered on the International Union for Conservation of Nature (IUCN) Red List of Threatened Species (Kyne et al. 2019), could most effectively support recovery of the species in its native range. Using the Guidelines on the Use of Ex Situ Management for Species Conservation (IUCN/SSC 2014), the participants agreed on a suite of ex situ and in situ management activities that would help to prevent the species' extinction in the wild, support existing wild populations through demographic and genetic augmentation from aquarium-bred individuals, and address key conservation knowledge gaps via targeted research, training, and education (Abel et al. 2024). This workshop has been regarded as a defining moment in the ongoing collaborative effort to save the species from extinction.

One of the many recommendations crafted during the ECA workshop was to conduct a population viability analysis (PVA) for the species across the in situ – ex situ integrated management spectrum. A PVA analysis would provide key insights for, among other things, identifying primary demographic drivers of bowmouth guitarfish population growth in both in situ and ex situ habitats, and for laying out quantitative targets defining strategies for augmenting existing populations or re-establishing populations in suitable habitat through the release of aquarium-born individuals.

More specifically, species managers were interested in exploring the following practical questions:

- What do species experts know about reproduction and survival of bowmouth guitarfish in the wild, and how can those data be used in a PVA context?
- What do species experts know about the population demographic and genetic structure of the current global ex situ aquarium population? How can we incorporate this information into an explicit viability analysis of the species in an integrated management framework?
- What are the most important demographic drivers of bowmouth guitarfish population growth?
- Given the desired goal of releasing aquarium-born pups to reinforce existing wild populations or to establish viable populations in the historic range where bowmouth guitarfish may currently be effectively absent, what are the target parameters of a release program (e.g., number of pups per annual release, duration and frequency of releases) that could be expected to promote in situ population viability?

Construction of the PVA began formally in January 2025 with a pair of online meetings of species experts across the in situ – ex situ spectrum, elasmobranch population biologists, and *Rhina* management authorities. These participants were invited to a PVA workshop to be hosted by Singapore Oceanarium in May 2025. The meetings of this global contingent were conducted in pairs to accommodate the wide range of time zones between all participants. In addition to the larger meetings that focused on more broad topics related to the population analysis, parallel meetings of a smaller group (the Model Development Team) were organized to discuss species data, model structure and function in finer detail. Virtual meetings of workshop invitees and the Model Development Team continued monthly through April 2025. A preliminary version of the PVA model was presented and discussed at the May 2025 workshop, with modifications and expansions made to the model based on participants' suggestions. A final pair of meetings with Model Development Team members was held in July to further refine the analyses. All in all, approximately 35 hours of online meeting time and 2.5 days of dedicated in-person workshop time were devoted to ensuring broad participation in the conceptualization and design of this analysis. The full list of online and in-person workshop participants is presented in Appendix I.

This document gives a detailed description of the PVA intended to address the management questions listed above. Following a brief introduction to the practice of population viability analysis and the specific tool used to conduct the analysis, a broad overview is presented of the structure and function of the simulation model describing bowmouth guitarfish population dynamics. Next, a detailed summary is provided of the input parameters that define the linked in situ – ex situ population model. Finally, the results of the analyses are summarized, including a review of the key assumptions built into the analysis and a list of conclusions drawn from those results that could be used to help design a release strategy.

Approach to Simulation Model Development

Using population viability analysis to inform species conservation management

PVA is a powerful suite of tools used by wildlife conservation researchers, non-government organizations, and national and regional government agencies to assess threats to endangered wildlife populations and to evaluate management options designed to improve population or species status in the wild (Beissinger and McCullough 2002; Morris and Doak 2002). These analyses typically rely on computer simulation modeling to project future wildlife population abundance and create a valuable framework for assessing the extent of species data available and how these data interact to drive population growth or decline. In particular, the process of conducting a PVA helps to stimulate information sharing and discussion among species experts and provides a neutral environment where assumptions about our collective understanding of the system of interest can be expressed and clarified.

That said, it is important to recognize that PVA methodologies are not intended to give indisputably absolute and accurate “answers” for what the future will bring for a given wildlife species or population. Many practitioners caution against the exclusive use of absolute results from a PVA when using the tool to recommend specific management actions for threatened populations (e.g., Ludwig 1999; Reed et al. 2002; Ellner et al. 2002; Lotts et al. 2004; Lacy 2019). Instead, we often rely on PVA results to make comparisons of the relative performance of a simulated population under alternative management activities or different assumptions of environmental conditions. Even in this comparative framework, however, results from PVA efforts can provide a critical base of evidence when deriving meaningful and justifiable quantitative targets for endangered species recovery (Himes Boor 2014; Doak et al. 2015).

Choice of software to conduct the PVA

As noted previously, population viability analysis is typically conducted using computer simulation modeling tools. The tool chosen for this analysis is Vortex (version 10.9.0: Lacy and Pollak 2025; Lacy et al. 2021). Vortex simulates the fate of each individual in a population, usually based on an annual cycle that features breeding, mortality, incrementing individual age, dispersal among subpopulations, removals (or emigration from the population), supplementation (managed or natural immigration), and truncation of population abundance if the abundance of individuals exceeds the specified carrying capacity (ceiling density dependence) (Figure 1). Stochasticity in demographic processes is modeled as annual variation in each demographic rate at the population level (environmental variation) and random, binomial sampling variation in the fates of individuals (demographic stochasticity) (Lacy 2000a, 2000b). An advanced optional feature of Vortex allows the user to define individual, population, or global state variables to derive complex expressions for age/sex-specific demographic rates, which can change over time in response to evolving environmental conditions, management regimes, etc. The software includes a facility to incorporate metapopulation structure, with multiple populations linked through natural or managed dispersal. Individual fates are aggregated to output describing projected population sizes (mean, SD, and distribution across independent iterations), population growth rates, population age and sex structure, and probabilities and times to local extinction or quasi-extinction (abundance falling below a user-defined threshold size).

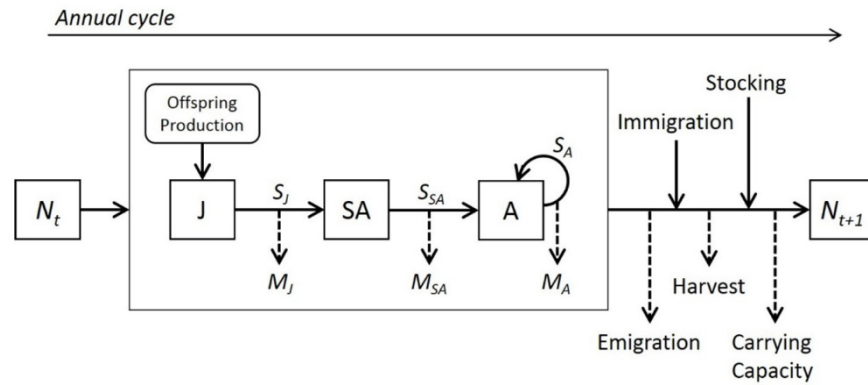


Figure 1. Generalized diagram showing the series of events making up a typical annual cycle (timestep) in the PVA software package Vortex, representing simulated change in population abundance N from year t to year $t+1$. Enclosed portion shows the production of juveniles (J) and the transition of individuals among the juvenile, subadult (SA) and adult (A) stages, determined by annual age-specific survival (S_x) and their complementary mortality rates M_x . Processes displayed above the timeline to the right of the diagram increase population abundance, while those below decrease abundance. For more information on Vortex, see Lacy and Pollak (2025) and Lacy et al. (2021).

Vortex projects the effects of population structure on loss of genetic diversity through drift, and in turn the impacts of loss of diversity on fecundity and survival (and, hence, population growth) via processes such as inbreeding depression. This emphasis on population genetic components of long-term population viability is a key defining feature of Vortex in comparison to other PVA simulation software. Furthermore, Vortex includes a detailed set of routines that simulate genetic management processes in intensively managed zoo and/or aquarium populations. These ex situ populations can then be used explicitly as a source of individuals to be chosen for release to wild habitats. Known genetic relationships among individuals in the ex situ population, tracked using studbook data management tools, can be directly incorporated into the aquarium component of the model. In this way, gain or loss of genetic diversity can be tracked in a realistic fashion over time to evaluate the impacts of population management choices on overall population viability.

For more detailed information on the features of Vortex and its application to wildlife population management, see Lacy (2000; 2019) and Lacy et al. (2021).

General overview of bowmouth guitarfish PVA model structure: Populations

As described in the Introduction, the primary goal of this population demographic analysis is to explore a range of strategies for improving bowmouth guitarfish population viability in a defined habitat site in the species' native range through the release of individuals produced in the global aquarium population. Given this goal, it is instructive to describe the high-level structure of the Vortex model, and the assumptions built into that structure to facilitate its use for bowmouth guitarfish integrated management. More details about this structure are found in the following section summarizing model input.

At the most basic level, the simulation model used here is composed of three distinct population components: (1) a wild site, yet to be chosen as of the implementation of this PVA, to which aquarium-born bowmouth guitarfish are released; (2) three sets of regional aquaria that can serve as the source of bowmouth guitarfish to be released to the wild site; and (3) a generic wild source population that is the origin of wild animals that are occasionally added to the regional aquarium population in order to improve its genetic diversity. Key attributes of these three simulated populations are discussed below.

1. **Wild site** – Ideally, this site would be located within the Indo-Pacific region, roughly between the eastern coast of India and an eastward extension of the Wallace Line that broadly delineates Asian and Australasian faunal regions. More specifically, the boundary selected for this analysis extends northward to the east of the Philippines, in the spirit of the faunal balance boundary proposed by Mayr (1944). Therefore, the region for the proposed wild site would include waters belonging to nearly all of Southeast Asia; Indonesia west of Sulawesi and Lombok; the Philippines; and China, Taiwan and Japan. Pending the results of population genetic analysis of selected individuals held in Asia regional aquaria, the southeastern boundary could be extended to include sites such as the Raja Ampat Marine Protected Area off the coast of West Papua (Figure 2). This region was chosen based on the knowledge that a large proportion of bowmouth guitarfish currently housed in aquaria were sourced from this region, primarily around Taiwan and Indonesia (more on this in the description of the regional aquaria population below).

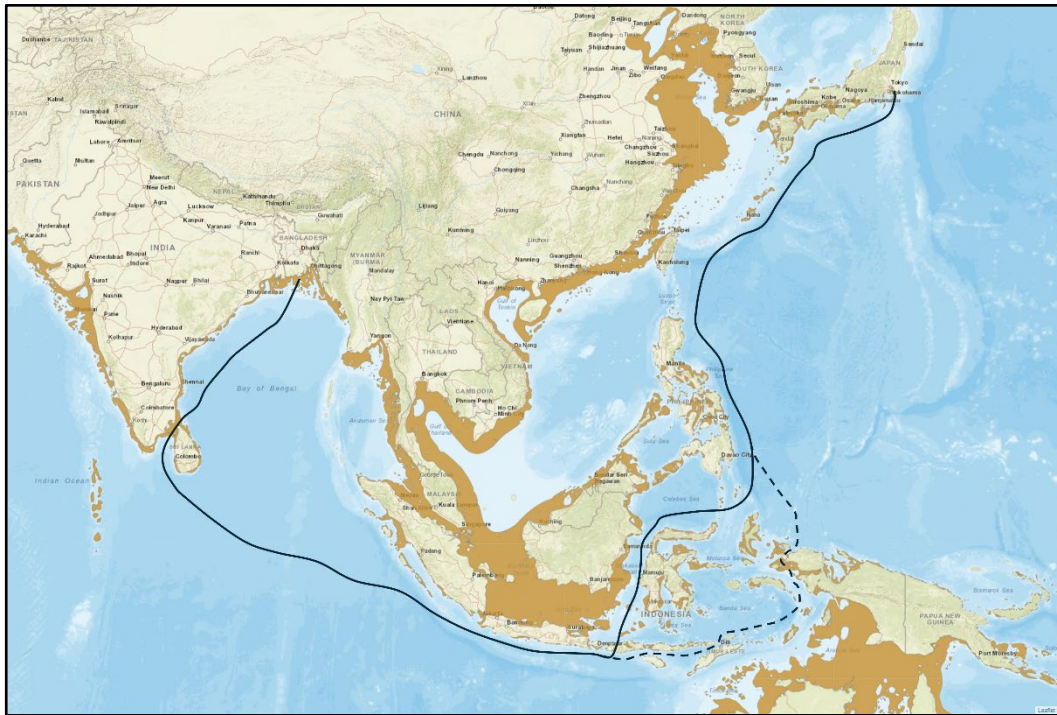


Figure 2. Approximate regional boundary for selection of release sites for bowmouth guitarfish in Asia. Dashed line represents the possible eastward extension of this boundary pending results of genetic analysis of individuals held in regional aquaria. Base map adapted from the global distribution map used in the current Red List assessment (Kyne et al. 2019), with darker brown areas designating known resident populations. See text for more information.

Efforts to identify an exact location for this wild site remain ongoing. Consequently, this PVA does not include detailed site-specific information on key attributes such as a site's current abundance or carrying capacity. Given that a specific release site is not identified, this analysis adopts a conservative approach to translocation (release) planning by assuming that the wild site is unoccupied. An estimate of carrying capacity would depend on the spatial extent of the area and an expression of its overall habitat quantity and quality. Without this specific information, the current analysis uses a generic value for this parameter. The analysis also assumes that the wild site is within a well-managed Marine Protected Area (MPA), meaning that anthropogenic activities leading to higher levels of bowmouth guitarfish mortality are largely absent. In other words, using the language of fisheries population demographic analysis (e.g., Gulland 1969), fishing mortality is assumed to be negligible in the wild

site ($F = 0$), resulting in total mortality (Z) approximately equal to natural mortality (M). More information on these assumptions is presented in the following section describing PVA model input.

Finally, the use of a generic wild site for this analysis means that detailed information on ecological conditions governing bowmouth guitarfish population growth is largely unknown. Consequently, there are no site-specific data on age-specific mortality to use in the PVA model. To address this issue, the analysis includes a set of four alternative population demographic profiles. These profiles describe a range of in situ conditions that collectively define plausible bowmouth guitarfish population growth rates:

- High growth: Favorable ecological conditions promote robust levels of population growth (long-term mean annual deterministic growth rate $\lambda = 1.08$, equivalent to a mean 8% increase in the population annually);
- Low growth: Modest ecological conditions promote intermediate levels of population growth (long-term mean annual deterministic growth rate $\lambda = 1.04$);
- High growth-El Niño: The high growth profile with the addition of the El Niño – Southern Oscillation climatic event that reduces long-term population growth (long-term mean annual deterministic growth rate $\lambda \approx 1.06$); and
- Low growth-El Niño: The low growth profile with the addition of the El Niño – Southern Oscillation climatic event that reduces long-term population growth (long-term mean annual deterministic growth rate $\lambda \approx 1.02$).

Built into the simulations featuring the El Niño profiles is the assumption that the frequency of these climatic events will gradually increase over time. This expectation is a feature of many data-driven global climate models that examine the potential consequences of pervasive climate change (e.g., Cai et al. 2014).

2. Regional aquaria – In keeping with the desire to align the genetic origin of selected individuals making up the global aquarium bowmouth guitarfish population with the location of the wild release site(s), this analysis includes only those aquaria that are known through molecular genetic analysis to have bowmouth guitarfish in their collection that were sourced from the geographic region described above. Institutions housing animals with an unknown geo-genetic origin are currently excluded from the PVA, although ex situ work continues to collect and analyze those genetic data to determine if they could be added to the analysis.

Animals of the appropriate geo-genetic origin are distributed among approximately 20 aquaria in three identified regions: the United States, Europe, and Asia. Breeding animals of the same geo-genetic origin that are distributed in aquaria across the world is logistically quite challenging. Consequently, this PVA considers these three regions as distinct subpopulations of the global ex situ bowmouth guitarfish metapopulation. The precise characteristics of animals within each regional population were specified from current studbook data, thereby creating an accurate portrayal of the contemporary age-sex composition and genetic structure of the global ex situ population.

Additionally, it is assumed that established technologies such as artificial insemination (AI) will be adapted to the bowmouth guitarfish system in the short term, with the potential to facilitate breeding across geographic boundaries and, consequently, moving towards a truly global ex situ population. Therefore, the regional aquarium population component of the PVA features a “coalescence” event into a single ex situ population after eight years from the onset of the simulation in 2026.

Finally, the PVA assumes a modest level of long-term growth in the regional ex situ populations – specifically, long-term mean annual deterministic growth rate $\lambda \approx 1.04$. Because the long-term breeding management of bowmouth guitarfish remains in its infancy, it is currently unclear if this anticipated level of growth can be achieved.

It is important to note here that this PVA is not designed to serve as a comprehensive demographic and genetic management plan for the global ex situ population. A dedicated planning effort using separate analytical tools (e.g., PMx: Ballou et al. 2025) and focused deliberations among the aquarium community managing bowmouth guitarfish would be required to achieve that goal.

3. Wild source – This third population component represents a largely undescribed in situ bowmouth guitarfish population, outside the boundaries of the wild release site, from which animals are occasionally removed as fisheries bycatch and transferred to the Asia regional aquarium population to improve its ex situ genetic diversity. The viability of this source population is not germane to this analysis; it is solely included as a source of animals for regular addition to the ex situ population component.

General overview of bowmouth guitarfish PVA model structure: Release mechanics

Broadly speaking, the core feature of this PVA is the collection of appropriate individuals from the ex situ population and their transfer to and release into the wild site. The chosen cohort for this release is pups slightly younger than one year of age. Key factors to evaluate in the specification of a potentially successful release strategy include: the number of pups to release; the duration of those releases, i.e., over how many years those releases will take place; and the frequency of releases, i.e., the number of years between release events.

As additional detailed features of the release event, the PVA models include:

- A gradual increase from the current low survival rates of pups often observed in aquaria; and
- A gradual improvement in pup survival during the transport, holding and post-release phases of the release effort.

These mechanics represent a conservative approach to simulating the release event, in which the early years of the effort may see comparatively low success rates. However, through targeted improvements in husbandry and release techniques, the production and survival of released pups can increase from relatively worst-case scenarios to sustained best-case scenarios over a defined period of time.

A simple schematic of the structure of this PVA analysis is given in Figure 3.

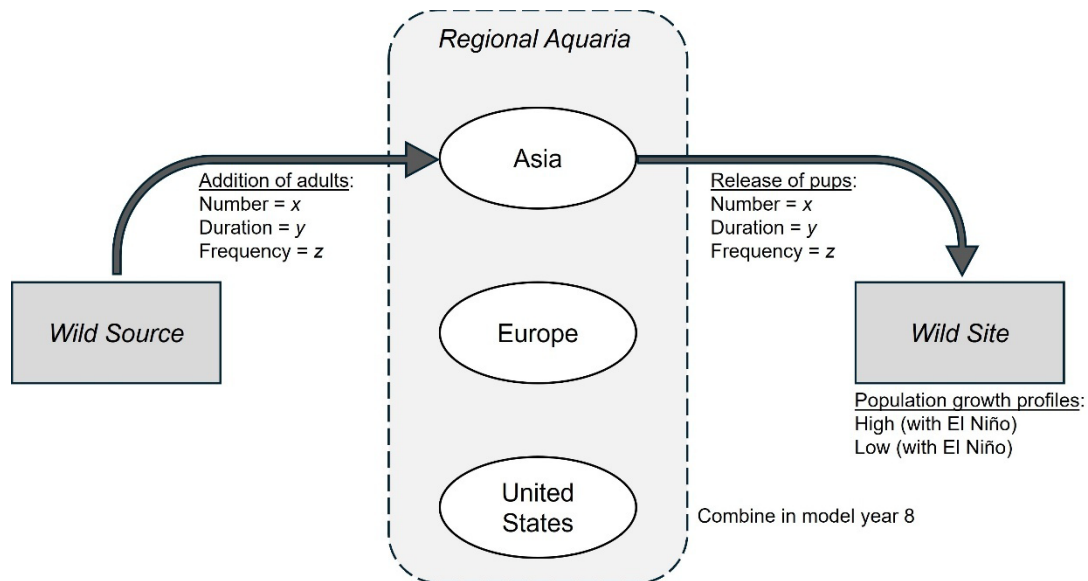


Figure 3. General schematic of the bowmouth guitarfish PVA, showing the population components and the basic elements of the release and augmentation strategies. See accompanying text for more detailed information.

Bowmouth Guitarfish PVA Model Input

This section gives additional detail on the core numerical input used in the PVA models used for this analysis. A summary of the input parameter values can be found in Table 2 at the end of this section, with a more detailed presentation of more complex model elements given in Appendix III.

General simulation characteristics

Each of the individual model scenarios – defined by a unique set of input parameters as described below – was run using 1000 replicates. This iterative procedure is necessary as each replicate will yield a different outcome resulting from random annual variation in expected rates of breeding and survival in the simulated bowmouth guitarfish population. Each scenario was projected forward for 50 years, a timeframe considered long enough to observe reliable trends in demographic and genetic performance under alternative management options.

Initial population size, structure and carrying capacity

Wild release site: The key questions for the PVA presented earlier in this document included identifying core parameters of a release program that would successfully augment existing wild bowmouth guitarfish populations or, where appropriate, re-establish a viable population where the species had been reduced to such low numbers as to be locally non-viable. Without identifying a specific release site, and in the absence of detailed data on bowmouth guitarfish abundance in particular parts of the species' range, this analysis adopts a conservative approach to evaluating opportunities for promoting population persistence. Therefore, the initial abundance of bowmouth guitarfish in the generic wild site is set at zero. When a specific site has been chosen for dedicated release planning, the current analysis should be revised to include detailed information in available on the resident bowmouth guitarfish population abundance, age-sex structure, growth rate, etc. To briefly explore the impact of this approach on wild population viability, an alternative scenario is created in which the initial bowmouth guitarfish abundance in the wild is assumed to be 20 individuals. This population is mostly adults, representing a situation where this small population currently has low reproductive success owing to low population density.

Similarly, the carrying capacity (K) – the long-term maximum population abundance that a defined habitat can support – is set somewhat arbitrarily at approximately 1000 total individuals. To be consistent with the expression of carrying capacity in the ex situ population (see below), K is more precisely defined as the number of adults supported in the habitat. Given the reproduction and survival rates used in this analysis, the number of adults present in a population at demographic equilibrium is roughly 40% - 45% of the total population size. Therefore, K for the wild site is set at 425 adults.

Regional aquaria: The global ex situ population is initially divided into three regional subpopulations: United States, Europe, and Asia. This subdivision was employed to more accurately reflect the challenges of pairing adult bowmouth guitarfish across institutions distributed across the globe.

It was recognized that animals destined for release should have a geographic-genetic ancestry that aligns with the location of the chosen release site, which is to be located east of the India coastline and west of the Wallace Line as described in an earlier section of this report. Therefore, the ex situ population used in this analysis is restricted to only those institutions that care for animals with the correct ancestry. Institutions housing animals with currently unknown geo-genetic ancestry are also excluded from this analysis.

The details of each population as defined at the start of the simulations are given in Table 1. A full specification of this regional ex situ population, including parentage of each animal along with its age,

sex, and regional location, was summarized in a studbook text file and imported into Vortex to specify a realistic structure of this population component. See Appendix II for a full description of this file.

To estimate carrying capacity (number of adults) for each regional ex situ subpopulation, it was assumed that each institution was capable of housing four adults (assumed to be roughly equivalent to two males and two females given the demographic rates as described below). Therefore, K for each region was derived by summing this maximum adult abundance across the full complement of institutions. For the carrying capacity calculation, the two institutions in the United States for which the geo-genetic ancestry of their animals is currently unknown are added to the current institutions to generate a list of “potential institutions”. This assumes that these institutions would confirm the geo-genetic ancestry of their animals and, if necessary, could revise their collection in support of increasing the regional population of bowmouth guitarfish of the desired geo-genetic ancestry. Similarly, the number of institutions in the Asia region that could potentially house bowmouth guitarfish of the appropriate ancestry was generously set at 15 assuming the confirmation of the ancestry of individuals currently in those additional nine aquaria. Using this logic, the carrying capacity for the three regions in Table 1 was initially set to 60 (Asia), 36 (Europe), and 32 (United States) adults.

Table 1. Characteristics of the global ex situ bowmouth guitarfish population as specified in the PVA. Animals included in this population component are known to have been sourced from the geographic region in the Indo-Pacific where a release site is to be chosen. Aquaria currently housing animals of the desired geo-genetic ancestry are tallied in the “Current Institutions” column, and institutions capable of housing these animals are added to generate the data in the “Potential Institutions” column.

Regional Subpopulation	Total Abundance	Adults (M.F)	Unique Founders Represented	Current Institutions	Potential Institutions
Asia	28	6.10	17	6	15
Europe	12	2.5	7	9	9
United States	21	2.3	7	6	8
TOTAL	61	10.18	31	21	32

Consultation with population managers led to considering the likelihood of effectively applying artificial reproductive technologies to enhance bowmouth guitarfish breeding across institutional geographic boundaries. To evaluate the potential benefit of this proposal – both for increasing the number of pups that could be produced for release to the wild, as well as to improve the genetic diversity of a global ex situ population – the PVA simulations feature a coalescence of the three regional populations into a single global population in model year 8, corresponding approximately to calendar year 2033. The actual physical location of individuals does not change; instead, the Dispersal mechanic in Vortex allows for individuals in the United States and Europe regional populations to be “moved” into the Asia population. As a result of this mechanic, opportunities for breeding are significantly increased as gametes (typically sperm) could be transported to institutions in different regions. A small number of alternative scenarios is created to explore the consequences of a failure to implement this coalescence, thereby maintaining the three separate regional aquarium populations throughout the duration of the simulations.

Wild source: The initial abundance of this generic population was set at 200 individuals (approximately 84 adults), which was large enough to ensure consistent population growth as desired. Carrying capacity for this population was set at 425 adults, identical to the wild release site habitat.

Age-class specification

Throughout this report, the following definitions will be used to classify individual bowmouth guitarfish on the basis of age:

- Pup (juvenile): Age-0 (birth) to Age-1
- Subadult: Age-1 to Age-5
- Adult: Age-5 and older

Reproduction

Wild release site: Reproduction is defined in the model as the birth of live pups, i.e., pups that die in utero and stillborn pups do not figure into the calculation of reproductive rates. As a general characteristic, bowmouth guitarfish are polygynous breeders, with a single male capable of breeding with multiple females in a year. Consequently, abundance of males is not typically a limitation to breeding success in this model, although more nuanced density-dependent phenomena may be present in actual wild populations. Bowmouth guitarfish are considered to be capable of breeding throughout their adult lifespan, starting at five years of age (defined as first pups born). The maximum breeding age in wild populations is unknown; estimates range from approximately 19 (ICAR-CMFRI 2022) to 23 years of age, with the latter estimate being consistent with an expected generation length of about 15 years as calculated for large-bodied wedgefishes in the current IUCN Red List assessment (Kyne et al. 2019). The higher estimate of 23 years was chosen for this analysis.

Given the general life history of the species, we assume that all adult females and males have an equal opportunity to pair in any given year. In other words, there are no specific physiological or behavioral barriers to pairing among adults. While the species can be classified as an annual breeder (e.g., Purushottama et al. 2022a), there is some evidence that females may skip a year of pup production in response to ecological conditions (ICAR-CMFRI 2022). In order to generate the desired set of population demographic profiles as described in a previous section of this report, the proportion of adult females that produce pups in a given year was set to 40% for the High growth profile and 38% for the Low growth profile. This rate of production is lower than those values reported in the literature for this species but is consistent with the estimated survival rates derived from individual growth data (described in more detail below).

While the data on pup production are variable, it is estimated that successfully breeding females produce a brood of 2-14 pups, with a mean of about 5 pups (Raje 2006; Last et al. 2016; Purushottama et al. 2022b). Note that the maximum end of this range is based on a wild-caught female caught in a set net off the coast of Taiwan (F. Fan, personal communication); the probability of producing a litter of this size among all reproducing females is considered quite small. The mean sex ratio among pups in a litter was taken to be 50:50, although some data sources cite departures from this expectation (Purushottama et al. 2022b: 148 embryos from 29 gravid females, sex ratio (female:male) = 1.3:1, no significant difference from parity).

Regional aquaria: Because of the small number of litters produced among bowmouth guitarfish in the ex situ environment, reliable data on breeding tendencies and frequencies is not yet available. In light of this situation, all but one of the reproductive parameters for the regional aquaria populations are identical to those for the wild release site. The one different parameter value is the proportion of successful adult females that produce a litter of pups, which was increased slightly to 46% in keeping with the desired population demographic profile of $\lambda \approx 1.04$.

Wild source: Demographic rates for this generic source population were calibrated to achieve a Low growth population profile. Therefore, all reproductive rates were identical to the wild release site

population with the exception of using a lower rate of litter production among successfully breeding females, equal to 38%.

Mortality

Wild release site: Mortality in Vortex is defined as the probability of an individual of age x (here measured in years) dying before reaching age $x+1$. In all population components, we assume that male and female mortality rates are equivalent.

Given the mean reproductive rates and the target growth rates that define the two High growth and Low growth population profiles as discussed above, mortality rates were calculated indirectly using standard fisheries stock assessment methods and adjusted as necessary. The age-dependent mortality estimator M_x developed for elasmobranchs by Peterson and Wroblewski (1984) was used to initially derive estimates for the High growth population profile. This estimator is expressed mathematically as

$$M_x = 1.92w_x^{-0.25}$$

where w_x is the mean weight at age x . This age-dependent weight parameter is itself derived from established length-weight analyses using the von Bertalanffy growth function and informed by basic demographic parameter estimates for bowmouth guitarfish (von Bertalanffy 1957). Pup and subadult mortality rates were specified for each age, while the above function was used to express mortality across the adult stage. For the Low growth population profile, all age-specific mortality rates were multiplied by a constant (1.135) to reduce expected population growth to the desired value.

When calculating these age-specific mortality estimates for the High growth population profile, it is assumed that total mortality Z is essentially equal to natural mortality M , meaning that fishing mortality F , commonly considered in fisheries stock assessments, is effectively zero. This would be the optimal outcome of strong bycatch mitigation efforts in the type of Marine Protected Area (MPA) that should be identified as a wild release site candidate. In contrast, an inherent assumption in creating the Low growth population profile is that fishing mortality, and likely other undescribed ecological and/or anthropogenic factors, are no longer negligible and act to increase total mortality.

Regional aquaria: In the absence of specific data to the contrary, the analysis assumes that the same set of age-specific mortality rates apply to each regional aquarium population. To achieve the desired mean growth rate for the ex situ population component ($\lambda \approx 1.04$), the age-specific mortality schedule for subadults and adults used in the wild release site (High Growth scenario) was increased by a factor of 1.17. Pup mortality in the regional aquarium population was treated differently. Current rates of pup mortality are quite high and likely reflect some type of dietary deficiency and/or other husbandry-related factors in the ex situ environment. To reflect this current situation, the demographic projections are initiated with a mean pup mortality of 70%. However, the expectation is that the issues contributing to this high mortality rate will be resolved in the near future, resulting in higher survivorship rates that may converge on rates expected in wild populations. Specifically, the models include a time-dependent function in which pup mortality is expected to decline in a linear fashion from 70% in model year 1 to 40% after five years (i.e., model year 6).

Wild source: Age-specific mortality rates for this generic population were adjusted from the baseline values defining the High growth profile to result in a mean annual population growth rate of $\lambda = 1.04$, i.e., the Low growth profile.

For all populations, environmental variability (EV) is added to each age-specific mortality rate in the form of a beta-distributed standard deviation applied to the mean rate. The standard deviation is approximately 20% of the mean rate (coefficient of variation = 0.2), simulating random fluctuations in the

mean rates from one year to the next resulting from unpredictable variability in environmental determinants of mortality (smaller-scale climatic effects, prey and/or predator densities, etc.).

Other population demographic characteristics

Inbreeding depression: All populations are assumed to be subject to the detrimental effects of inbreeding, which is modeled here as a reduction in survival among inbred pups. The strength of inbreeding depression is expressed as the number of lethal equivalents (LEs) distributed across the species' genome. In the absence of species-specific research, analyses like this one rely on meta-analyses across many species for which data on inbreeding levels and accompanying detrimental impacts can be measured, typically in controlled ex situ environments. These analyses conclude that a typical wildlife population would carry approximately six lethal equivalents, with about half of those LEs composed of recessive lethal genes (O'Grady et al. 2006). While relatively little is known about inbreeding depression in elasmobranchs, it is prudent to adopt a conservative approach in an analysis of this type and assume it could be present. Consequently, the value cited above is used in all populations. Note, however, that this detrimental impact occurs only when inbreeding becomes relatively pronounced in a population; if rates of inbreeding are negligible, inbreeding depression is not a factor influencing future population growth.

Correlation of environmental variation (EV) in demographic rates within and among populations: Vortex allows for correlation of the direction and strength of environmental variation between reproduction (probability of breeding) and age-specific survival. In this way, years that are good or bad for reproduction can also be similarly good or bad for survival as a general property of the species' life history. The present PVA sets this level of correlation at 0.5, indicating a moderate level of correlation. Additionally, EV can be correlated among populations. This correlation is set to 0.0 as environmental conditions determining survival in the wild would typically be independent of those governing survival in the ex situ aquarium environment.

El Niño catastrophic event: The global phenomenon known as the El Niño – Southern Oscillation can significantly impact winds and sea surface temperatures over the tropical Pacific Ocean. These impacts can lead to major interruptions to normal rainfall and temperature patterns, and have also resulted in significant impacts to marine habitats including coral bleaching (França et al. 2020). Taken together, the broad research on impacts of El Niño events on tropical marine systems justifies the inclusion of this event as a single-year catastrophe-type element in this PVA.

Vortex allows for the specification of both the frequency of this type of event, as well as the quantitative impact on both reproduction and survival. An often-cited frequency for this event is every four to seven years (e.g., NOAA Physical Sciences Laboratory website: psl.noaa.gov), although the evidence underlying this estimate is difficult to obtain. To assess the general impacts of this event, the PVA assumes that the current frequency of El Niño in the tropical Pacific Ocean is approximately once every 10 years (annual probability of occurrence = 0.1). It is believed that this frequency will increase, however, due to the various forces driving global climate change. Therefore, the El Niño frequency is assumed to increase in the PVA in a linear fashion to once every five years (annual probability of occurrence = 0.2) over the next 25 years.

If the simulation determines that an El Niño event occurs in a given year, the analysis assumes that the normal rate of reproduction would be reduced by 15%, and each age-specific survival rate would be reduced by 10%. Specific evidence to justify these severity estimates for existing bowmouth guitarfish populations does not exist. Similar survival impacts have been used in a recent PVA of the Maugean skate (*Zearaja maugeana*) in Australian waters (Grant et al. 2023). Reproductive impacts would likely result from reduced quality of the marine environment including decreased food availability, etc. These conditions could also reduce the survival of bowmouth guitarfish, but a primary mechanism for reduced

survival would be increased fishing pressure by local human populations, and associated increases in bowmouth guitarfish bycatch rates, as enhanced food insecurity leads human communities to ramp up fishing efforts and other means of procuring food.

Genetic management of the aquarium population: Management of ex situ populations typically seeks to reduce the rate of loss of population genetic diversity, typically through selection of unrelated pairs whenever possible to avoid inbreeding. Maintenance of accurate studbook records is key to implementing this management strategy. Vortex allows the user to set a limit for the relatedness or kinship between prospective parents. This PVA includes a threshold kinship level of 0.249, thereby prohibiting pairings between siblings or parent-offspring combinations.

Release scenario mechanics

Most of the model scenarios making up this PVA involve releasing individuals from the aquarium population to the wild release site. The Translocation module in Vortex is well-suited to simulate this task, as specific individuals can be selected for collection from one population and transferred to a different population with their demographic and genetic characteristics retained.

In order to better assess the design of a proposed release program, this PVA includes a large number of scenarios defined by different combinations of key variables making up that program. The release process is conducted as follows:

- Pups are to be chosen for release.
- Participants at the May 2025 PVA workshop constructed an expected timeline for the translocation procedure, noting that pups are likely to be approximately four months of age when they are selected for release. Consequently, in the Vortex annual cycle the translocation event takes place after the natural mortality event. This will potentially reduce the number of pups available for release, but is considered to be a more realistic portrayal of the true annual timeline.
- Releases are expected to begin in year 1 of the simulation, and continue for a total duration of 10, 15, or 20 years.
- Over the total duration of the release program, the time interval between releases is one year (i.e., annually), two or three years.
- In each year targeted for releases, a specified proportion of pups produced in that year – 25%, 50% or 75% – are selected for translocation. During the first seven years of the simulation, while each regional aquarium remains a separate breeding population, pups are selected from the Asia regional aquarium population. Starting in model year 8, when use of artificial reproduction techniques is possible and the aquarium population becomes a single global breeding population, pups are considered to be selected from that global population. The specific mechanism of producing and transporting pups to the Asia region for release is not explicitly considered in this PVA. The goal of this simulation element is to consider a set of expanded opportunities for producing genetically healthy pups that can not only improve retention of genetic diversity in the aquarium population but can also increase breeding opportunities to release more pups to the wild.
- Prior to the release event, the model imposes an additional mortality to simulate any issues that might arise during transport to and residency in a holding facility. Pup survival during this time interval begins in model year 1 at 70% and gradually increases to 90% over a 10-year period to simulate improved methods for transport and temporary holding. These values represent the range of expected survival rates estimated by species management experts at the May 2025 PVA workshop.
- Surviving pups are then translocated to the wild release site. Immediately after release, there is a separate mortality imposed to simulate the cost of any issues that may arise after holding and release. This post-release survival rate begins at 50% in model year 1 and gradually increases to

90% over a 10-year period. Once again, these values represent the range of expected survival rates estimated by species management experts at the May 2025 PVA workshop.

Augmentation of the aquarium population

An assumption built into the PVA is that bowmouth guitarfish will continue to be caught in fishing gear and, consequently, a small number could be made available for introduction into local aquaria for genetic enhancement of the ex situ population. To simulate this process, a pair of five-year-old adults (the youngest adult age class as specified by Vortex) is selected from the wild source population and translocated to the aquarium population. This process begins in model year 5, and animals are added at five-year intervals until model year 25. In the first augmentation event, the adults are introduced into the Asia regional aquarium population; after the coalescence of the aquaria in model year 8, the animals are considered to be part of the global aquarium population, although their specific location is undefined. While the pair of selected adults might by chance be related to each other, the model assumes that animals in the wild source population are unrelated to individuals in the aquarium population.

Scenario Structure Used in PVA Simulations

The primary part of this PVA is based on a total of 108 distinct scenarios, with each scenario defined by the set of input parameters discussed in the previous sections. Within each of the four wild release site population demographic profiles, there are 27 scenarios across the range of values specifying the size of the release cohort, the duration of the release program, and the interval between releases. Through exploring the full range of possible variables that define a proposed release program, managers can be better informed about thresholds for characteristics that may contribute to desired levels of program success.

A diagram of this scenario structure is presented in Figure 4.

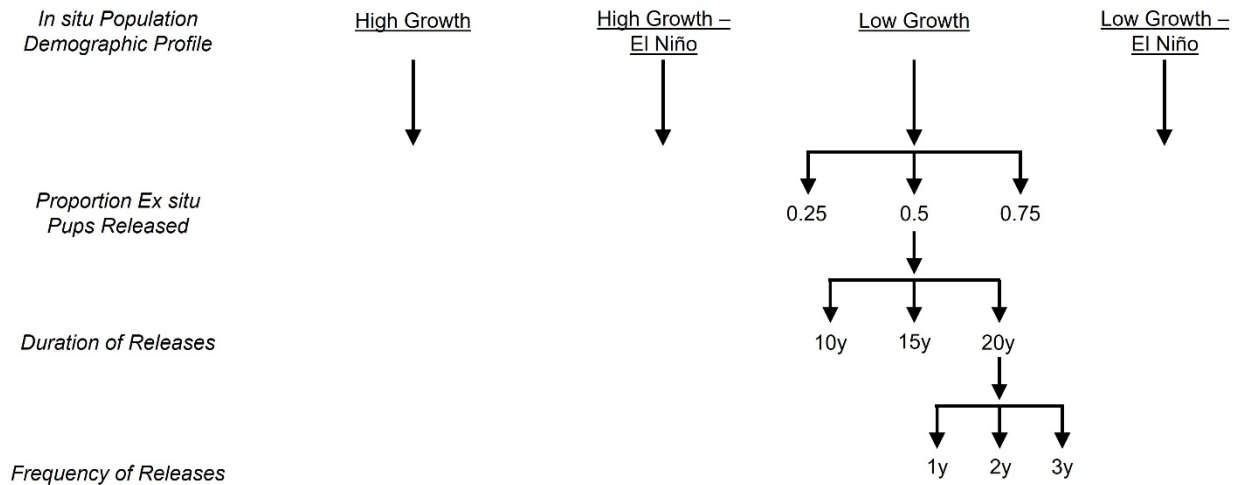


Figure 4. Workflow diagram for the primary set of scenarios comprising the bowmouth guitarfish PVA. “10y” refers to a total release program of 10 years, while “1y” signifies an interval of one year between releases. See accompanying text for more information on scenario definitions.

Table 2. Summary of population demographic input parameters for the bowmouth guitarfish PVA.

Input Parameter	Parameter Value			
	Wild Release Site		Regional Aquarium	Wild Source
	High growth	Low growth		
Initial population size	0	0	61*	250
Carrying capacity (adults)	425	425	Years 1-7: Asia 60; Europe 36; US 32** Years 8-50: Global 128	425
Reproduction				
Breeding system	Polygynous			
First breed age / maximum age	5 / 23			
% Adult females available for breeding	100			
% Adult females producing a litter	40	38	46	38
Litter size	Range 2 – 14 (Mean: 5.1)			
Litter sex ratio	50:50			
% Mortality (mean (SD))***				
Pup (0-1)	38.4 (8.0)	43.58 (9.0)	70 (9.0) (Year 1); 40 (9.0) (Year 5)	43.58 (9.0)
Subadult (1-2)	24.9 (5.0)	28.26 (5.5)	29.13	28.26 (5.5)
Subadult (2-3)	19.5 (4.0)	22.13 (4.5)	22.82	22.13 (4.5)
Subadult (3-4)	16.6 (3.5)	18.84 (3.7)	19.42	18.84 (3.7)
Subadult (4-5)	14.7 (3.0)	16.68 (3.3)	17.2	16.68 (3.3)
Adult (5+)	$100 \cdot (0.1926 \cdot (\text{Age}^{-0.251}))$; $100 \cdot (0.2 \cdot (0.1926 \cdot (\text{Age}^{-0.251})))$	$100 \cdot (1.135 \cdot (0.1926 \cdot (\text{Age}^{-0.251})))$; $100 \cdot (0.2 \cdot (1.135 \cdot (0.1926 \cdot (\text{Age}^{-0.251}))))$	$100 \cdot (1.17 \cdot (0.1926 \cdot (\text{Age}^{-0.251})))$; $100 \cdot (0.2 \cdot (1.17 \cdot (0.1926 \cdot (\text{Age}^{-0.251}))))$	As in Low growth profile
Inbreeding depression	6.0 lethal equivalents; 50% recessive lethals			
Catastrophe (El Niño)	Selected scenarios	Selected scenarios	None	None
Frequency	10% (Year 1); 20% (Year 10+)		NA	NA
Severity	0.85 (Reproduction); 0.9 (Survival)		NA	NA

* Includes only those aquaria known to care for bowmouth guitarfish originating from southeast Asia waters as per this report.

** Includes aquaria currently caring for bowmouth guitarfish of unknown geographic origin.

*** No difference in mortality rates between males and females.

Results of PVA Simulations

Output metric definitions

The presentation of PVA models results below will focus on the following output parameters:

- Mean population growth rate: The growth rate can be expressed as either an annual finite rate of change $\lambda = N_{t+1} / N_t$, or as the instantaneous per capita growth rate $r = \ln(\lambda)$. A population with a mean $\lambda > 1.0$ ($r > 0.0$) will grow in abundance over time, while $\lambda < 1.0$ ($r < 0.0$) indicates a declining population.
- Probability of population persistence: The proportion of iterations in a given scenario that do not decline to an abundance of zero, or that result in only one sex remaining in the population, at the end of the 50-year projection. Therefore, this is equivalent to $1 - (\text{probability of population extinction})$.
- Mean abundance of extant populations: Tables and figures report both total population abundance and the subset of the total that is comprised of adults. In both cases, abundance reported here for a given model scenario – known as N(Extant) – specifically tallies only those iterations in which the population persists as defined above. This metric was chosen from Vortex output instead of an alternate metric known as N(All) in which iterations that become extinct (effectively, an abundance of 0) are included in the calculation of the mean abundance. While informative in its own right, relying on N(All) does not accurately report the abundance of a population that escapes the destabilizing forces that can drive a small population to extinction (the “extinction vortex” of Gilpin and Soulé (1986)). That said, it is important to remember that the stated value of N(Extant) may represent a relatively small proportion of iterations in a given scenario that survive throughout the 50-year projection and, consequently, are likely to represent the relatively “lucky” set of circumstances that led to its persistence through time. Both persistence probability and N(Extant) are perhaps best interpreted using a statement such as “The likelihood of a population persisting over the time period of analysis might be relatively small but IF it persists, the abundance could be substantial”. It is important when reviewing results from any PVA analysis to fully understand the precise definitions of the output metrics and to interpret the output within the appropriate context.
- Mean proportion of initial gene diversity (GD) retained: Also known as expected heterozygosity, this metric tracks the proportion of gene diversity that is retained across the 50 years of the population simulation. Gene diversity is lost more rapidly in smaller populations that experience higher rates of inbreeding, which may lead to long-term declines in a population’s capacity to adapt to changing environmental conditions. Alternatively, GD can be gained through dispersal or supplementation of genetically unrelated individuals, and through mutation (not modeled here).

Performance of population demographic profiles

The base projections for each of the four identified population demographic profiles performed as expected (Figure 5). Stochastic growth rates for the simulations are:

- High Growth: $\lambda = 1.078$
- High Growth / El Niño: $\lambda = 1.055$
- Low Growth: $\lambda = 1.039$
- Low Growth / El Niño: $\lambda = 1.017$

In addition, the risk of the population declining to extinction is zero for each profile. Note that these growth rates are slightly less than the deterministic expectation described earlier in the description of model output. This is to be expected as stochastic variation in annual population demographic rates results in some instability in long-term population growth.

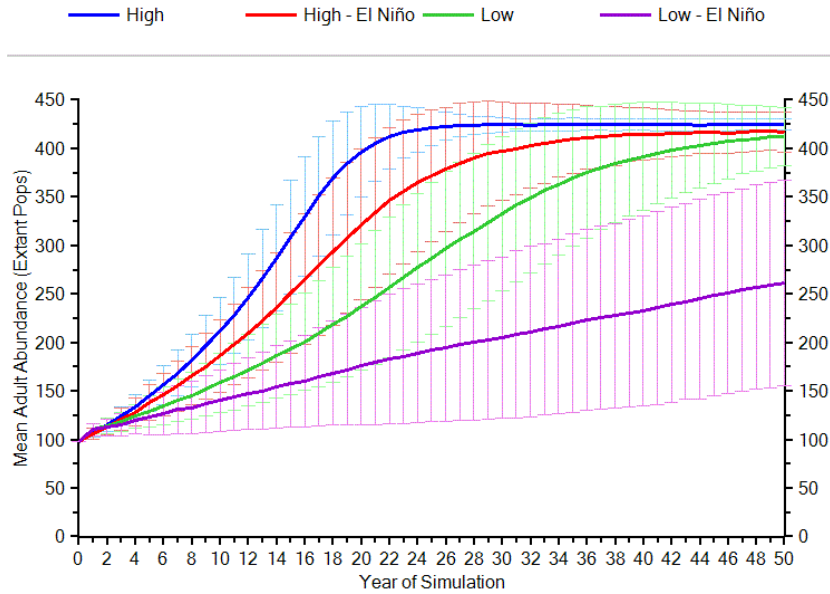


Figure 5. Adult abundance (mean±SD) for a hypothetical wild bowmouth guitarfish population under the four population demographic profiles.

Except for the Low Growth – El Niño profile, each of the projections approaches or reaches the assumed habitat carrying capacity of 425 adults (about 1100 total individuals) during the 50-year projection. Low Growth – El Niño projection is markedly more modest compared to the corresponding High Growth – El Niño profile projection, even though the proportional reduction in growth rate is effectively equivalent compared to the profiles without the El Niño (High Growth = 2.3% proportional reduction; Low Growth = 2.1% proportional reduction). This is a demonstration of the multiplicative nature of wildlife population growth dynamics.

Sensitivity analysis of wild population growth dynamics

Many of the demographic parameters for this PVA were estimated with at least a moderate level of uncertainty. This uncertainty is qualitatively different in character than the measures of variability included in mean rates of reproduction and survival, which represent annual fluctuations in environmental conditions that influence wildlife population demography. Understanding the impacts of our collective uncertainty in bowmouth guitarfish population dynamics can be important for prioritizing future data collection and targeted management activities.

In order to evaluate which demographic parameters have the largest impact on population growth, this PVA includes a demographic sensitivity analysis. Each of ten demographic parameters were sequentially varied proportionally across a range of plausible values, between 80% and 120% of their best baseline estimates and at 5% increments. Stochastic population growth rate (stochastic λ) was chosen as the output metric for analysis. The output was analyzed graphically by generating a “spider plot” showing stochastic λ for each scenario (nearly 70 in total). In addition, the simplified method of Crowder et al. (1994) was used for calculating the elasticity or proportional sensitivity of each demographic parameter. This method, based on more detailed methods for analyzing population matrix models (Caswell 2001), provides an additional numerical comparison of the relative change in population growth given a perturbation in each of the input parameters of interest. Elasticity for a given parameter x is calculated as:

$$E_x = \frac{\lambda_{(x+0.2x)} - \lambda_{(x-0.2x)}}{0.4 \times \lambda_x}$$

where λ_x is the growth rate estimated when parameter x is at the best baseline value.

Results of this sensitivity analysis are given in Figure 6 and Table 3. Graphically, parameters with the largest relative sensitivity are those with the steepest slope across the range of tested values. These parameters include subadult mortality, probability of litter production among adult females, and mean litter size. [A negative slope indicates an inverse relationship between a parameter like mortality and population growth rate, while a parameter like size shows a positive relationship with stochastic λ .] Numerically, the normalized elasticity values confirm what can be seen in the figure. Subadult mortality emerges as the parameter with the largest relative elasticity, followed by mean litter size, probability of litter production and mean pup sex ratio at birth.

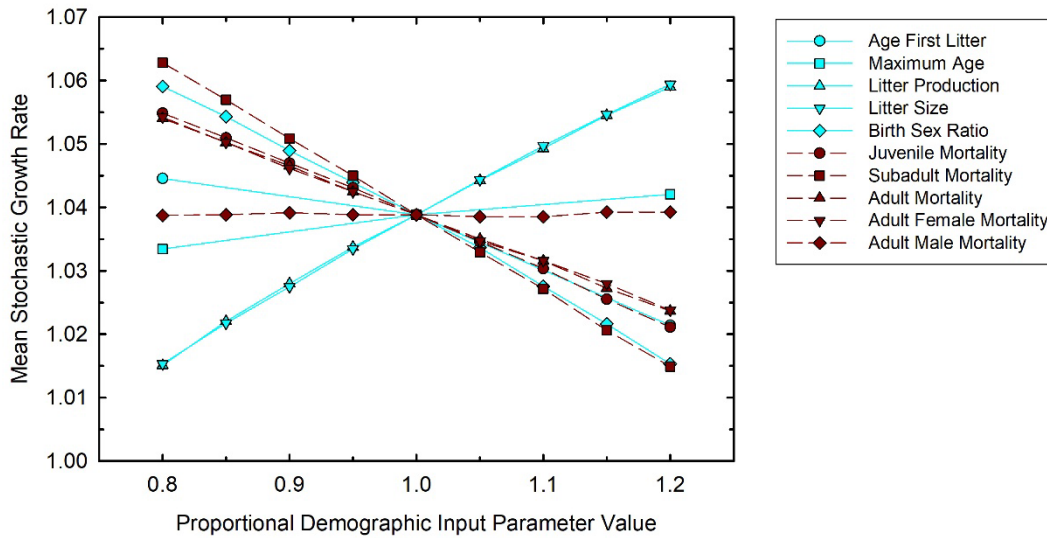


Figure 6. Results of demographic sensitivity analysis in the bowmouth guitarfish PVA. The central “body” of the spider plot gives the stochastic growth rate of the baseline scenario with each parameter at its best baseline estimate. Each data point represents an independent scenario featuring a specific parameter that is varied proportionally across a plausible range of values.

Table 3. Elasticity (proportional sensitivity) $E(x)$ of selected population demographic input parameters for the bowmouth guitarfish PVA. Values in the body of the table are stochastic population growth rates λ derived from independent scenarios featuring the input parameter in the column heading being varied across the range shown in the far left of the table. Abbreviations for input parameters align with those parameters defined in Figure 6.

Value	AFR	MaxAge	LitterProd	LitterSize	SexRatio	JuvMort	SubMort	AdultMort	AdFMort	AdMMort
0.8	1.0446	1.0334	1.0151	1.0153	1.0591	1.0549	1.0628	1.0540	1.0542	1.0387
0.85			1.0220	1.0217	1.0543	1.0510	1.0570	1.0502	1.0502	1.0388
0.9			1.0280	1.0275	1.0490	1.0470	1.0509	1.0466	1.0461	1.0391
0.95			1.0338	1.0334	1.0439	1.0431	1.0450	1.0425	1.0425	1.0388
1	1.0388	1.0388	1.0388	1.0388	1.0388	1.0388	1.0388	1.0388	1.0388	1.0388
1.05			1.0443	1.0444	1.0337	1.0346	1.0329	1.0350	1.0347	1.0385
1.1			1.0493	1.0497	1.0276	1.0304	1.0272	1.0316	1.0316	1.0385
1.15			1.0545	1.0546	1.0216	1.0255	1.0206	1.0273	1.0280	1.0393
1.2	1.0214	1.0421	1.0590	1.0594	1.0153	1.0211	1.0149	1.0237	1.0238	1.0393
$E(x)$	-0.0557	0.0207	0.1056	0.1061	-0.1053	-0.0812	-0.1152	-0.0730	-0.0733	0.0013
$E(x)$ -Norm	0.4832	-0.1799	-0.9160	-0.9206	0.9140	0.7045	1.0000	0.6335	0.6357	-0.0108

Release scenarios: Overview of population performance in selected scenarios

This section looks at results from a subset of release scenarios in an attempt to uncover general patterns of behavior in both the simulated wild release site population, as well as the aquarium population and its capacity to serve as a source of pups for release to the wild. The goal of examining this subset of scenarios is to uncover these general patterns without the need to present an exhaustive list of repetitive results across the entire suite of 108 release scenarios. In lieu of this, the reader is encouraged to review the detailed results of each scenario as presented in Appendix IV. In addition, this overview section is followed by a summary presentation of selected metrics across the full range of release scenarios. This summary is intended to give some insight into threshold conditions required to successfully establish a new population of bowmouth guitarfish in a selected site.

For this overview, the High Growth demographic profile is chosen as an underlying characteristic. Across this demographic profile, a set of scenarios has been chosen that often represents intermediate values of key input parameters defining the various release efforts. This choice can perhaps avoid presenting more or less extreme outcomes that could obscure more general patterns in population responses to different release strategies.

Number of pups released

Figures 7 – 11 assume an intermediate value for both the duration of a release program (15 years) and the interval of releases (2 years). Under these conditions, at the end of the 15-year release period there is a very high probability that a bowmouth guitarfish population is present and can subsequently persist across the 50-year timeframe of the projection (Figure 7). The early years of the effort result in rather low levels of success, but the continued release efforts act to reinforce the population and facilitate its persistence. When targeting just 25% of the pups produced in the Asia and later the global aquarium population, the wild release site population has a slightly reduced probability of persistence after the end of the release program. However, the likelihood of this population persisting for 50 years remains above 90%, with higher release rates resulting in persistence probabilities nearing 100%.

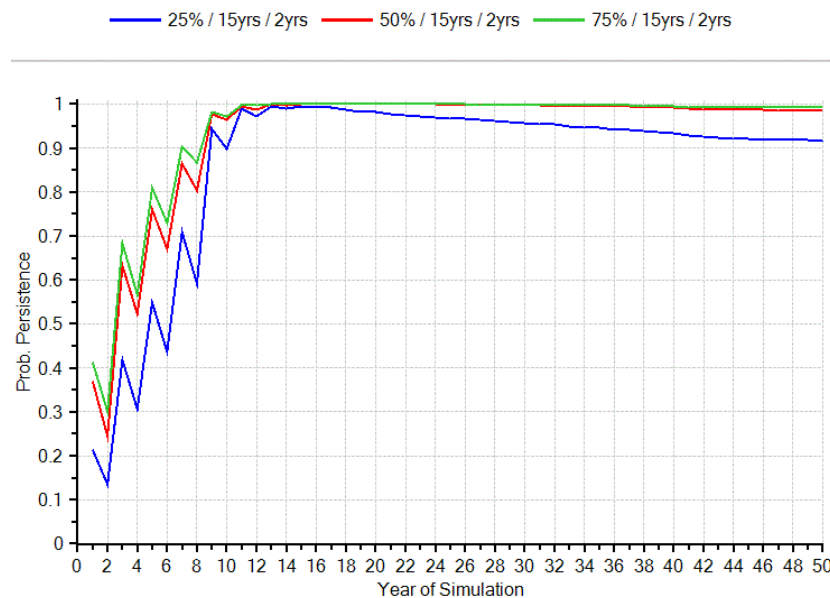


Figure 7. Probability of bowmouth guitarfish population persistence in the wild release site under different levels of release intensity (% aquarium pups released) and intermediate release duration and release interval.

Among those simulated populations that continue to persist at the wild release site, the number of adults is expected to grow to between 60 and 150 individuals, depending on the intensity of pup releases across the 15 years of the program (Figure 8). The stepwise increase in adults produced by the biannual interval of pup releases earlier in the projection is evident between model years 12 and 19. As with the persistence results shown in Figure 6, the adult population trajectory under the 25% pup release scenario is proportionally less robust than those scenarios featuring higher levels of intended pup releases. In addition, the impact of coalescing the aquarium populations in model year 8, which leads to increased pup production through enhanced breeding opportunities, is reflected in an increased growth rate of adult abundance in model year 13 as those released pups mature at five years of age.

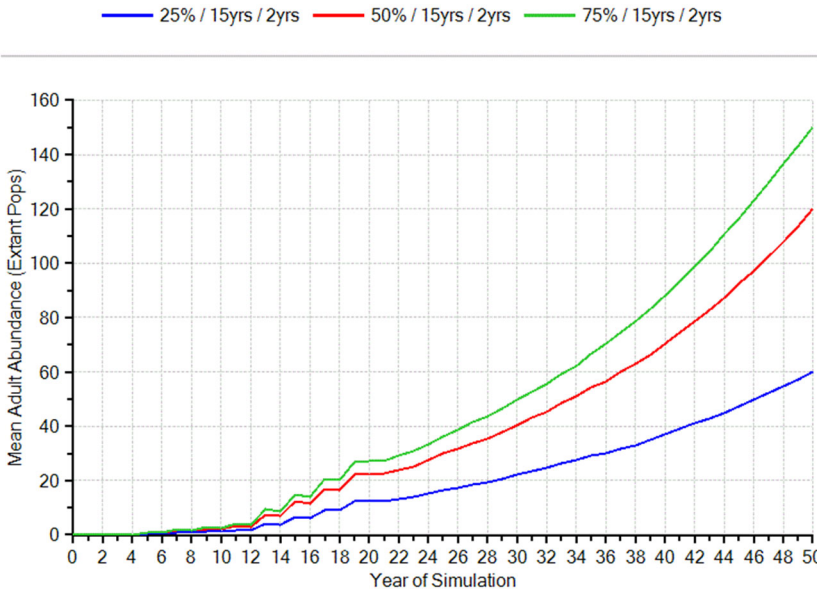
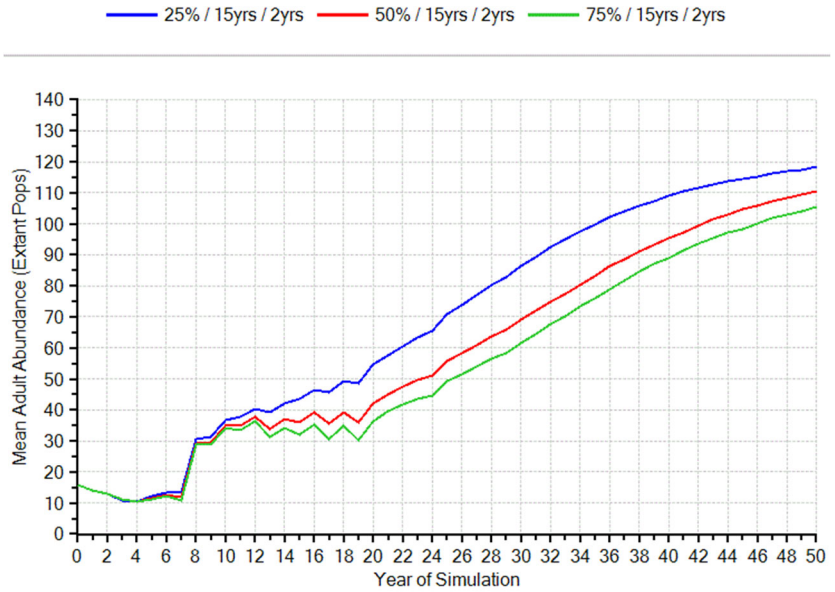


Figure 8. Mean abundance of adult bowmouth guitarfish in the wild release site under different levels of release intensity (% aquarium pups released) and intermediate release duration and release interval. Calculation of mean abundance includes only those projection iterations that persist.

The aquarium population shows a more distinct pattern in adult abundance, reflecting the simulated management decisions taking place early in the model trajectory (Figure 9). The figure tracks the abundance of adults in the Asia regional aquarium population in model years 1 – 7 and the global population after coalescence in model year 8 and beyond. Note here that the risk of extinction of this population is zero across the 50-year simulation. The Asia regional population exhibits a decline in adult abundance in the first phase of the trajectory, as a consequence of removing pups for release but more importantly the death of existing adults near their maximum lifespan in those first few years of the simulation. Beginning in model year 5, the adult population begins to increase slightly as pups born previously begin to mature. However, in model year 8 the population is larger as a result of the regional barriers to reproduction being largely removed as artificial reproduction comes online. Even with this coalescence, note that the adult aquarium population does not increase in abundance in model years 10 – 19 when at least 50% of pups produced are targeted for collection and release to the wild. After the release program is terminated in model year 15, the adult cohort begins to increase five years later as the more recent groups of pups begin to mature.

Figure 9. Mean abundance of adult bowmouth guitarfish in the aquarium population under different levels of release intensity (% aquarium pups released) and intermediate release duration and release interval. Calculation of mean abundance includes only those projection iterations that persist.



The number of pups collected from the aquarium population over the 15-year program shows the expected pattern given the two-year release interval (Figure 10). Of note here is the comparatively small number of pups collected in the first seven years of the program, with between approximately three and seven pups collected for release. When the aquarium population expands in model year 8, the number of available pups increases substantially to between approximately nine and 22 pups available for collection. As both the preceding production and mortality, and subsequent selection of pups is stochastic, it is possible that fewer pups than desired are available for selection. This explains the relatively smaller range in the total number of pups collected for release.

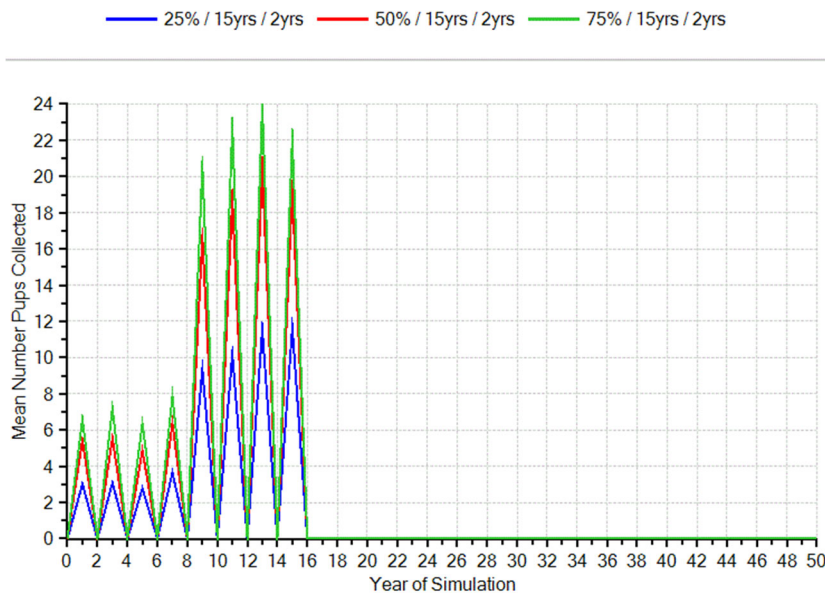


Figure 10. Mean number of bowmouth guitarfish pups collected from the aquarium population under different levels of release intensity (% aquarium pups released) and intermediate release duration and release interval.

Gene diversity retention in the aquarium population (Figure 11) declines comparatively rapidly in the first few years in the Asia regional population as older founder animals die. The addition of a pair of wild adults from bycatch in model year five results in a slight increase in mean population GD, but the large increase in gene diversity results from coalescence of the regional populations in model year 8. After this coalescence, the population shows a gradual erosion of GD as expected, with the loss proportionally smaller when fewer pups are selected for release. Note how the occasional addition of adults from bycatch in model years 15, 20 and 25 result in measurable increases in GD. Overall, gene diversity across the now global population remains above 0.9 for the entirety of the 50-year projection.

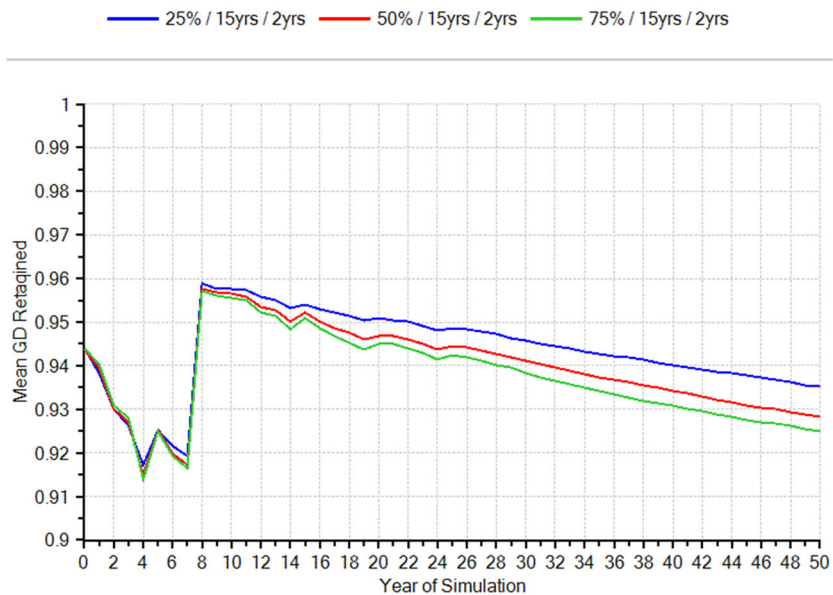


Figure 11. Mean gene diversity retained in the aquarium population under different levels of release intensity (% aquarium pups released) and intermediate release duration and release interval.

Duration of releases

Figures 12 – 15 assume an intermediate value for both pup release intensity (50%) and the interval of releases (2 years). Under these conditions, the shortest release program duration resulted in a rather substantial decline in the probability of population persistence at the end of the 50-year projection (Figure 12). The likelihood of wild release site population persistence at 50 years assuming a 10-year release program is approximately 70%, with that likelihood exceeding 95% for the 15-year and 20-year program duration scenarios. Mean adult abundance in the wild release site (Figure 13) shows a nearly identical pattern to the trajectories presented in Figure 8, with a slightly higher abundance in the release scenario extending to 20 years compared to the assessment of release intensity on final abundance.

Abundance of the aquarium population (Figure 14) shows a pattern similar to Figure 10 but with no real impact to population growth given that the release intensity is held constant at 50% of pups produced (this feature is seen in Figure 10). The coalesced global population is able to accommodate the intermediate level of pup collection for the release program, even in a 20-year program duration. This intermediate level of collection intensity can be offset by the assumed moderate growth of the ex situ population.

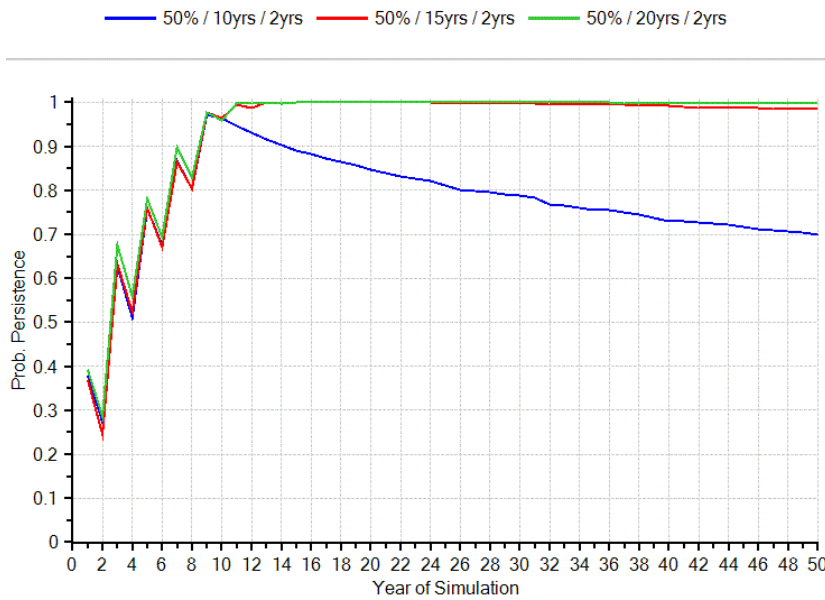


Figure 12. Probability of bowmouth guitarfish population persistence in the wild release site under different levels of release duration (years) and intermediate release intensity and release interval.

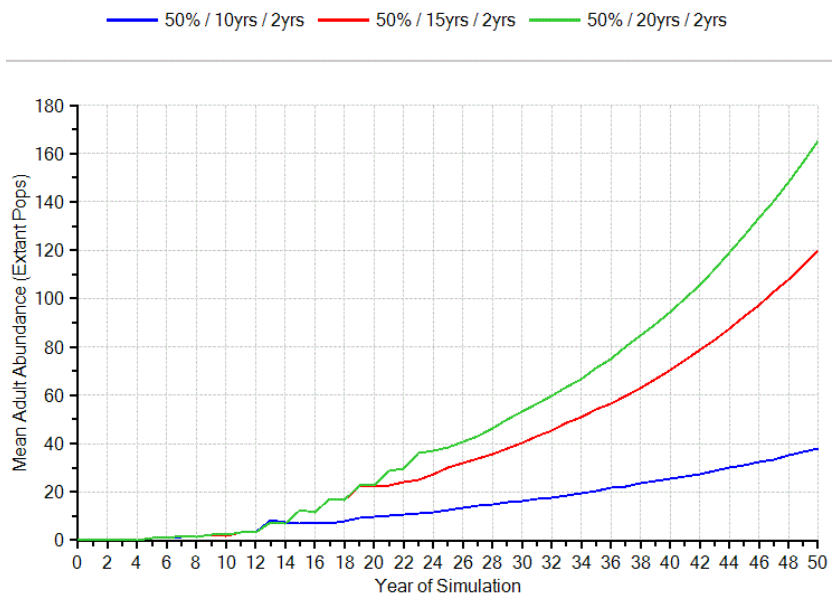


Figure 13. Mean abundance of adult bowmouth guitarfish in the wild release site under different levels of release site duration (years) and intermediate release intensity and release interval. Calculation of mean abundance includes only those projection iterations that persist.

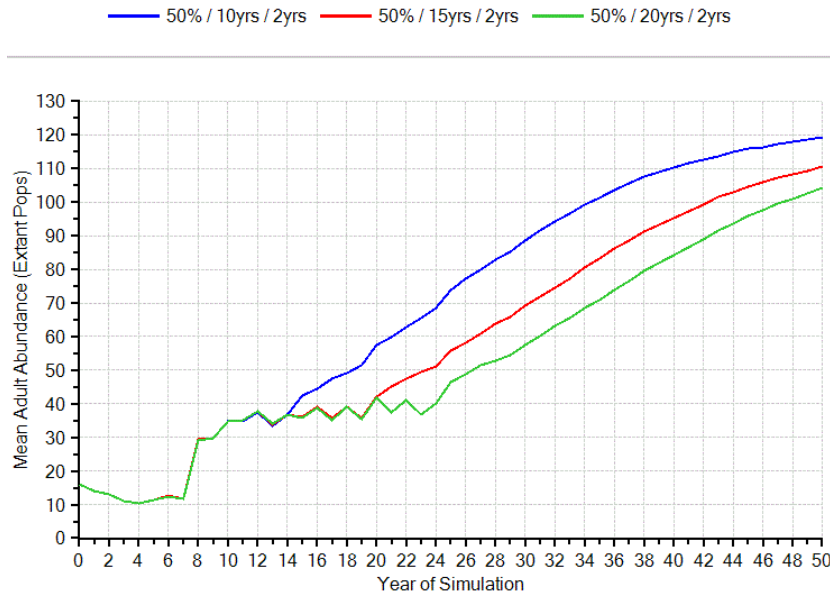
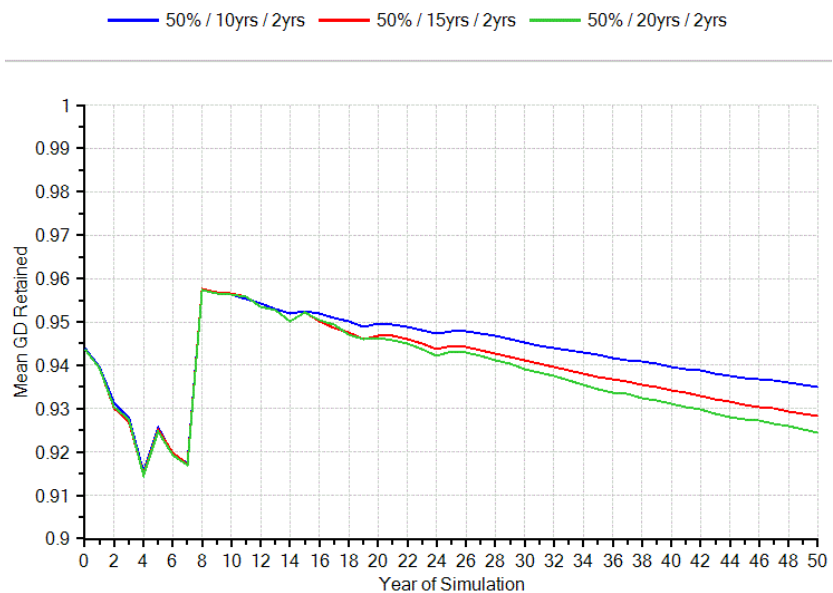


Figure 14. Mean abundance of adult bowmouth guitarfish in the aquarium population under different levels of release duration (years) and intermediate release intensity and release interval. Calculation of mean abundance includes only those projection iterations that persist.

The pattern for gene diversity retention under different levels of release program duration (Figure 15) is very similar to that presented in Figure 11 when comparing different release program intensities. A higher rate of pup collection and removal from the aquarium population leads to a lower recruitment rate of females into the adult population cohort and, consequently, moderate reductions in adult abundance (Figure 14) and retention of genetic variation. A persistent observation in these results is the relatively larger difference in model outcome between the lowest and intermediate values of a release program parameter – whether it is release intensity or release duration – compared to that difference between the highest and the intermediate values.

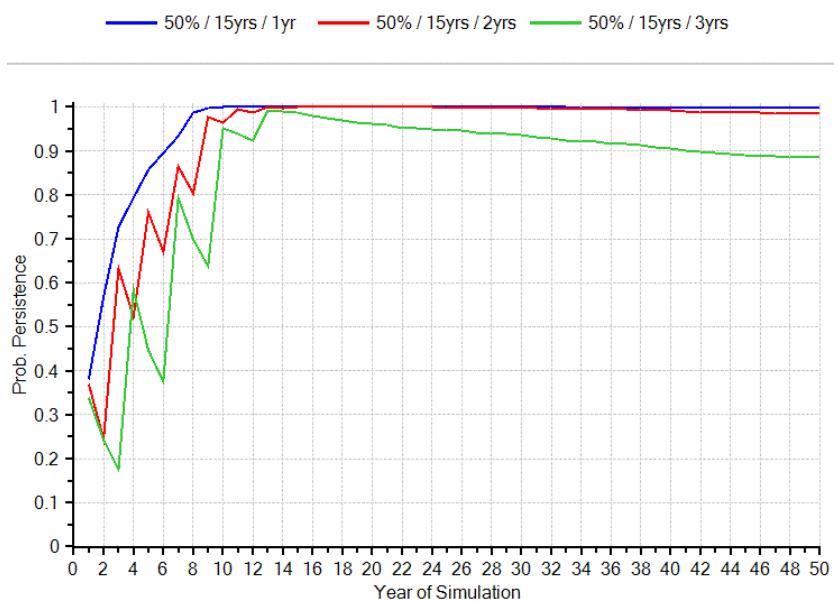
Figure 15. Mean gene diversity retained in the aquarium population under different levels of release duration (years) and intermediate release intensity and release interval.



Interval between releases

Figures 16 – 20 assume an intermediate value for both pup release intensity (50%) and the duration of releases (15 years). Varying the interval between releases leads to a larger difference in program success rate in the short term (e.g., years 1 – 10), which is not surprising given the rather high instability that often accompanies attempts to establish a new population (Figure 16). A release interval of three years allows the population to decline for a longer period of time before the next addition of pups, which can increase the risk of fledgling population extirpation until the next release event. As mentioned above, the likelihood of population persistence at 50 years is comparatively smaller when the release interval is three years, most likely the result of the smaller average size of the population if releases are successful (Figure 17). This smaller mean adult abundance is accompanied by a sizable variance, meaning that the risk of this population declining to very small numbers and ultimately extinction in the later years of the simulation is increased. This is seen quite clearly in Figure 16.

Figure 16. Probability of bowmouth guitarfish population persistence in the wild release site under different levels of release interval (years) and intermediate release intensity and release duration.



As in previous results discussed in this section (e.g., Figure 9), a higher frequency of pup collection events leads to a cessation of population growth and, in the case of annual collection, can contribute to short-term population decline (Figure 18). Despite this drop in adult abundance in the shorter term, the intrinsic capacity for robust population growth facilitates a strong rate of increase and no risk of population extinction.

The number of pups collected under different release intervals (Figure 19) displays a similar pattern as previous outcomes (Figure 10) but also highlights an interesting outcome for annual pup collection. An increased pup collection interval, featuring one or two years with no collection, likely allows for a larger number of subadults to recruit into the adult population, thereby producing more pups and facilitating a higher output for collection.

Gene diversity retention in the aquarium population (Figure 20) shows a very similar pattern to those scenarios previously discussed (Figures 11 and 15): a comparatively rapid decline in the first five years, followed by a marked increase after population coalescence and a later gradual decline with annual collection of pups resulting in the highest rate of genetic erosion. All measures of gene diversity in these scenarios exceed 90% retention over the course of the simulation.

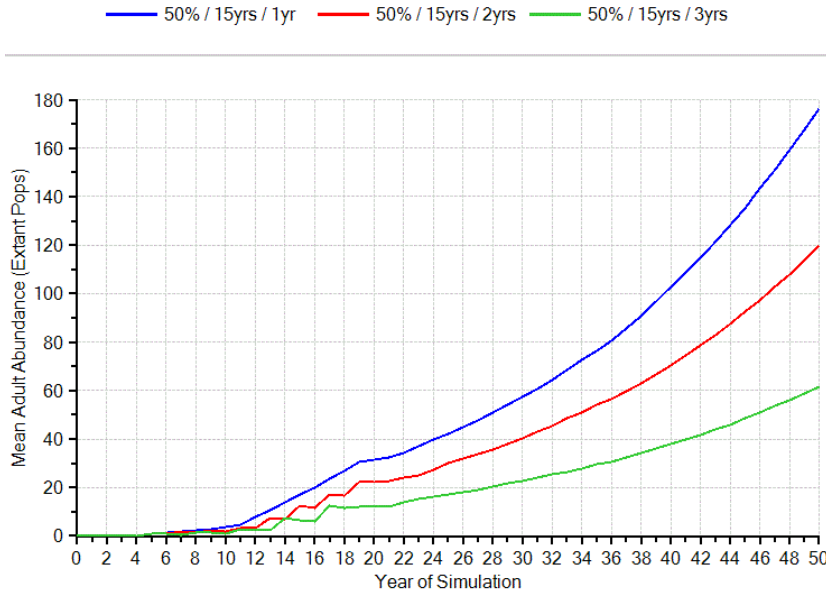
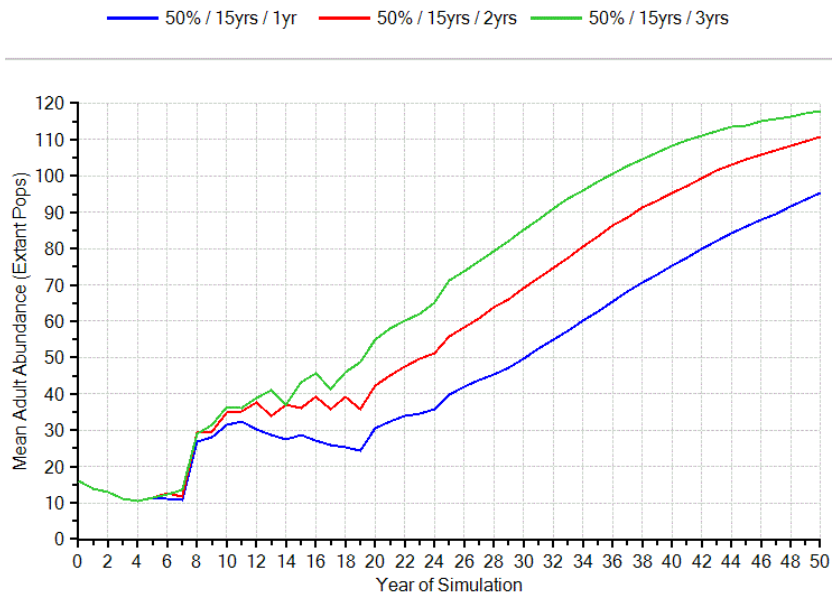


Figure 17. Mean abundance of adult bowmouth guitarfish in the wild release site under different levels of release interval (years) and intermediate release intensity and release duration. Calculation of mean abundance includes only those projection iterations that persist.

Figure 18. Mean abundance of adult bowmouth guitarfish in the aquarium population under different levels of release interval (years) and intermediate release intensity and release duration. Calculation of mean abundance includes only those projection iterations that persist.



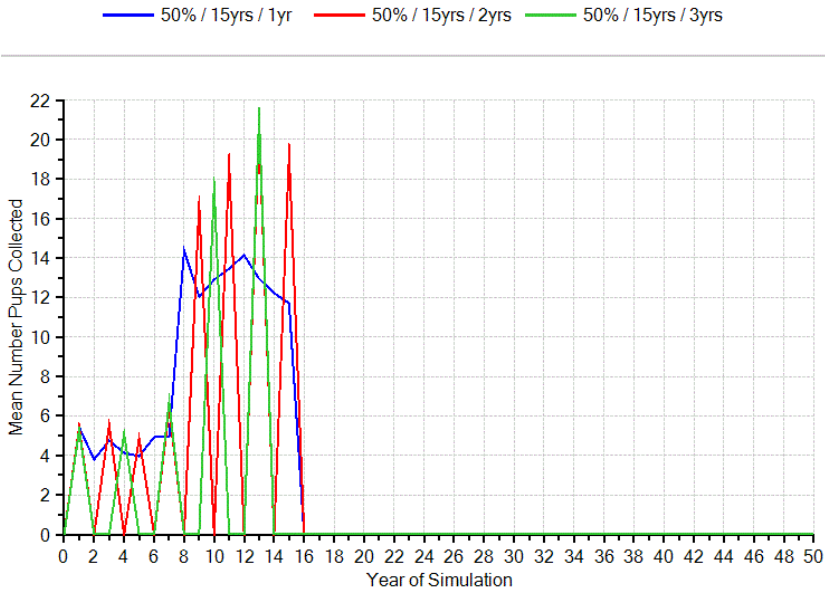


Figure 19. Mean number of bowmouth guitarfish pups collected from the aquarium population under different levels of release interval (years) and intermediate release intensity and release duration.

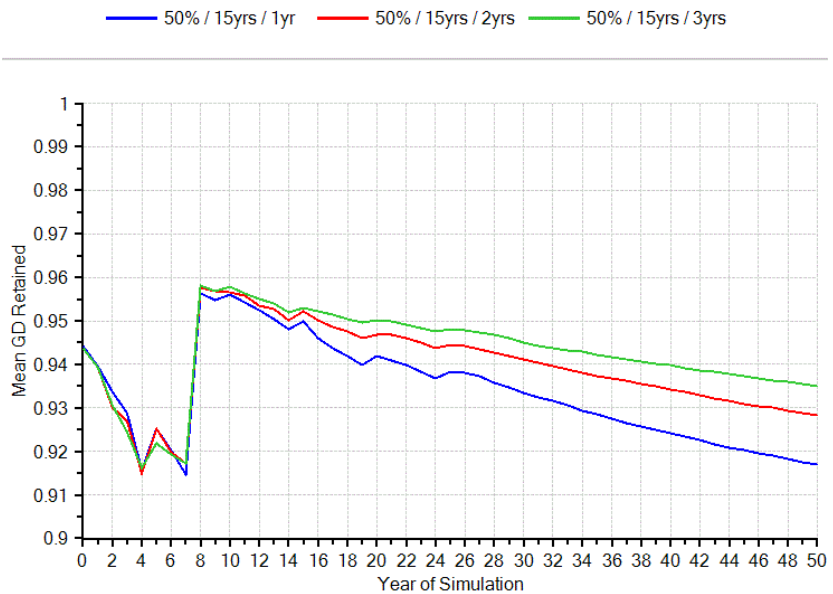


Figure 20. Mean gene diversity retained in the aquarium population under different levels of release interval (years) and intermediate release intensity and release duration.

Impact of the El Niño event

Including an El Niño climatic event affecting the wild release site, with an annual frequency increasing from 10% in model year 1 to 20% in model year 26, does not significantly impact the likelihood of population persistence in the wild at the end of the 50-year projection (Figure 21, top panel). A small decrease in population persistence probability becomes evident only at model year 20, which is five years after the cessation of the 15-year release event included in these scenarios. However, the abundance of adults at the end of the projection, among model iterations that persist for 50 years, is reduced by more than 50% when the climatic event is included (Figure 21, bottom panel). Once again, the difference

between the two abundance projections becomes evident after year 20 once pups born in the wild or released from the aquarium population around model year 15 reach maturity. The impact of the El Niño event on reproductive output and survival among all age classes results in a reduced population growth rate, although the simulated population remains capable of growing as a result of the robust capacity for growth in the High Growth population demographic profile.

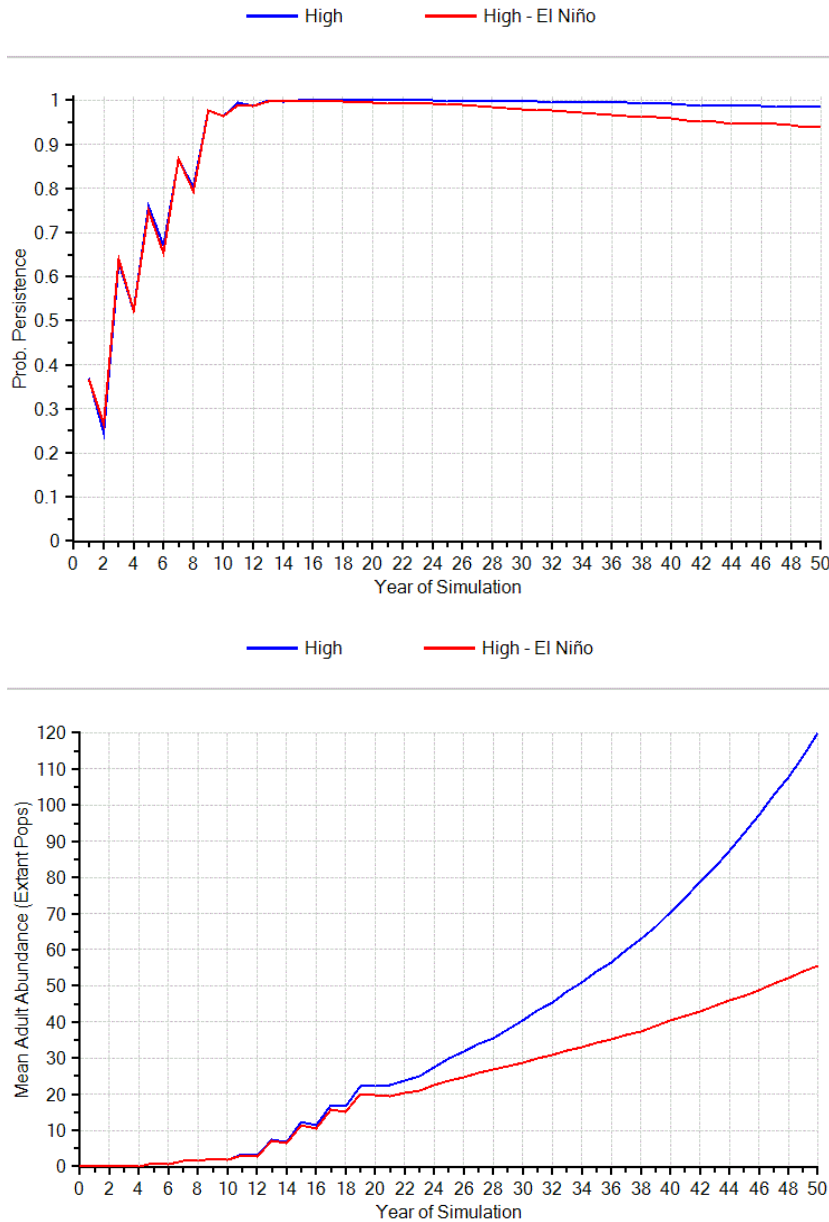


Figure 21. Probability of population persistence (top panel) and mean abundance of adult bowmouth guitarfish (bottom panel) in the wild release site governed by a High Growth population demographic profile and with or without the addition of an El Niño climatic event as described in the report text. The release scenario features a 50% pup collection intensity in the aquarium population, a 15-year release program duration, and a release interval of two years. Calculation of mean abundance includes only those projection iterations that persist.

Incorporating the El Niño event in the Low Growth population demographic profile produces a more significant impact on both probability of population persistence and, in particular, mean adult abundance (Figure 22). The probability of population persistence in the presence of the climate event drops to 75% after 50 years from a value of just under 90% in the absence of the event. More significantly, including the El Niño event results in a mean adult abundance trajectory that essentially

reflects a balance between the demographic capacity for population growth defining this profile and the severity factors defining the catastrophe as defined in the Vortex model. This balance leads to a population of adults that remains effectively constant at approximately 16 individuals beginning in model year 30 and continuing for the next 20 years of the projection. Even in the absence of the climatic event, this Low Growth profile results in a population that, after releasing about 50% of the available pups in the aquarium population every other year for the first 15 years of the simulation, grows to less than 35 adults after 50 years (Figure 22, bottom panel).

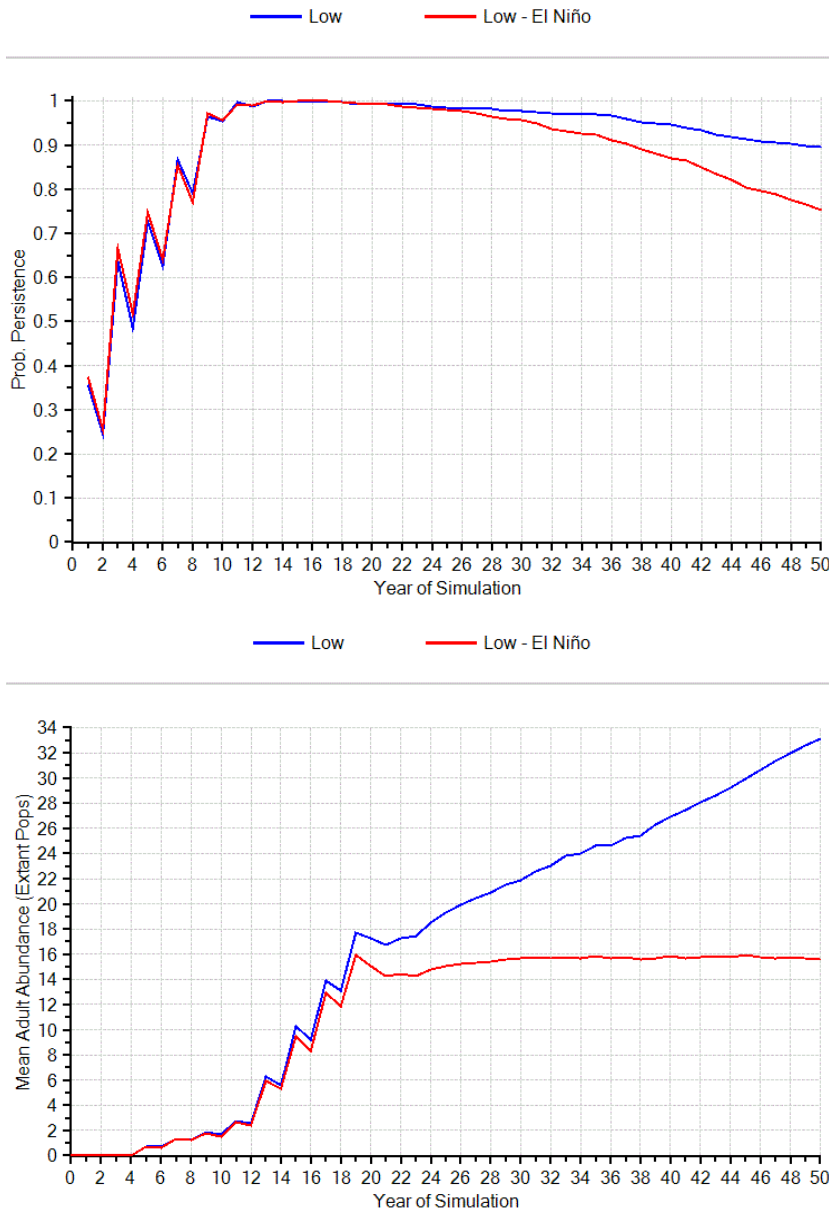


Figure 22. Probability of population persistence (top panel) and mean abundance of adult bowmouth guitarfish (bottom panel) in the wild release site governed by a Low Growth population demographic profile and with or without the addition of an El Niño climatic event as described in the report text. The release scenario features a 50% pup collection intensity in the aquarium population, a 15-year release program duration, and a release interval of two years. Calculation of mean abundance includes only those projection iterations that persist.

Impact of specifying an existing wild population at the release site

Key defining characteristics for this set of scenarios include:

- High and Low Growth demographic profiles for the wild population, excluding the El Niño event.
- Intermediate pup release profile: 50% of ex situ pup population collected in each event; release program duration of 15 years; release interval of two years.
- Initial abundance in the release site set at 20 individuals. All individuals are assumed to be adults, representing a situation where the remnant population is at a very low density and, therefore, has very low reproductive output. For context, this is the abundance used in the Indo-Pacific leopard shark (*Stegostoma tigrinum*) PVA commissioned for the StAR Project (Traylor-Holzer, 2021). Initially, the wild population has a very low rate of litter production, but this rate increases over a five-year period to simulate improving habitat conditions as well as the addition of aquarium-bred pups that help to stimulate improved reproductive success.

Implementing a release program at a site with an existing bowmouth guitarfish population, even when that population is assumed to be quite small, can significantly increase the prospects for continued wild population viability (Figure 23). The existing adult population declines over the first five years of the simulation in the absence of successful recruitment of younger animals but then begins to steadily increase beginning in year six as both pups that are released from the regional aquaria and those naturally produced in year one mature into adults. In both demographic profile scenarios, the final adult population abundance at 50 years is nearly three times larger when a small population of adults inhabit the release site at the beginning of the simulation. Moreover, the probability of population persistence (not shown here) remains low – roughly 0.25 to 0.8 in years two through eight – in the simulation in which the initial wild population abundance is zero. In contrast, the persistence probability remains high at 1.0 throughout the duration of the simulation for the scenario featuring the High Growth demographic profile and drops only very slightly to 0.997 after 50 years in the Low Growth demographic profile scenario.

Impact of no coalescence event among regional aquaria populations

Key defining characteristics for this set of scenarios include:

- Initial bowmouth guitarfish abundance in the wild release site is zero.
- High and Low Growth demographic profiles for the wild population, excluding the El Niño event.
- The coalescence in simulation year eight of the three regional aquaria populations into a single effectively global population through implementation of advance reproductive technologies, as described previously (see page 5), does not occur. In this case, the Asia regional population remains the sole source of pups for release to the wild.
- Maximum carrying capacity of the Asia regional aquarium population remains at 60 adults (four adults at each of 15 institutions) for the duration of the simulation.
- Intermediate pup release profile: 50% of ex situ pup population collected in each event; release program duration of 15 years; release interval of two years.

In the absence of the coalescence event, adult bowmouth guitarfish abundance at the release site is markedly reduced in both demographic growth profiles (Figure 24). Final adult abundance at 50 years is reduced by approximately 60% when the coalescence event does not occur, when compared to the original scenario when the coalescence is included in the simulation. After 20 years, which is five years after the last pup releases have taken place and those surviving individuals enter the adult cohort, the number of adults in the wild population in the “No Coalescence” scenario is about half the number

observed in the “Coalescence” scenario. The resulting rate of increase in the adult population is markedly lower when this coalescence event does not occur.

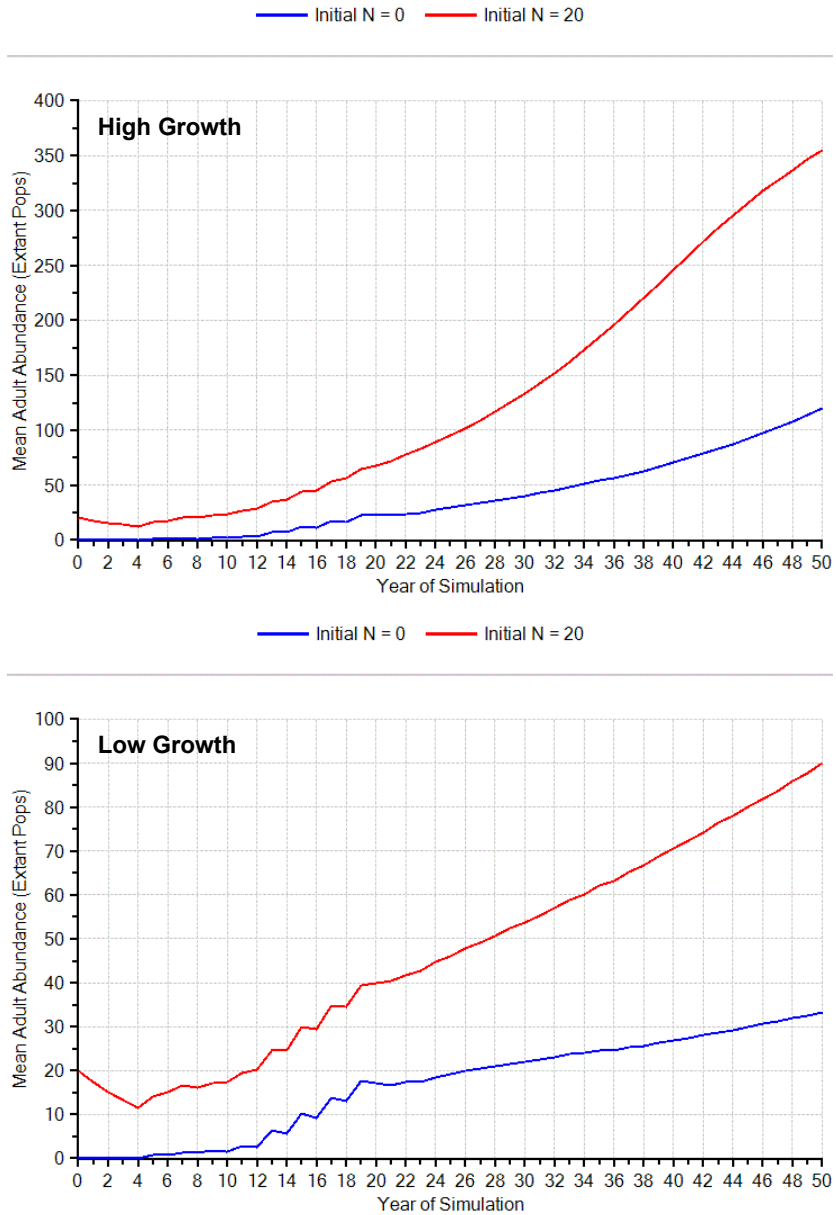
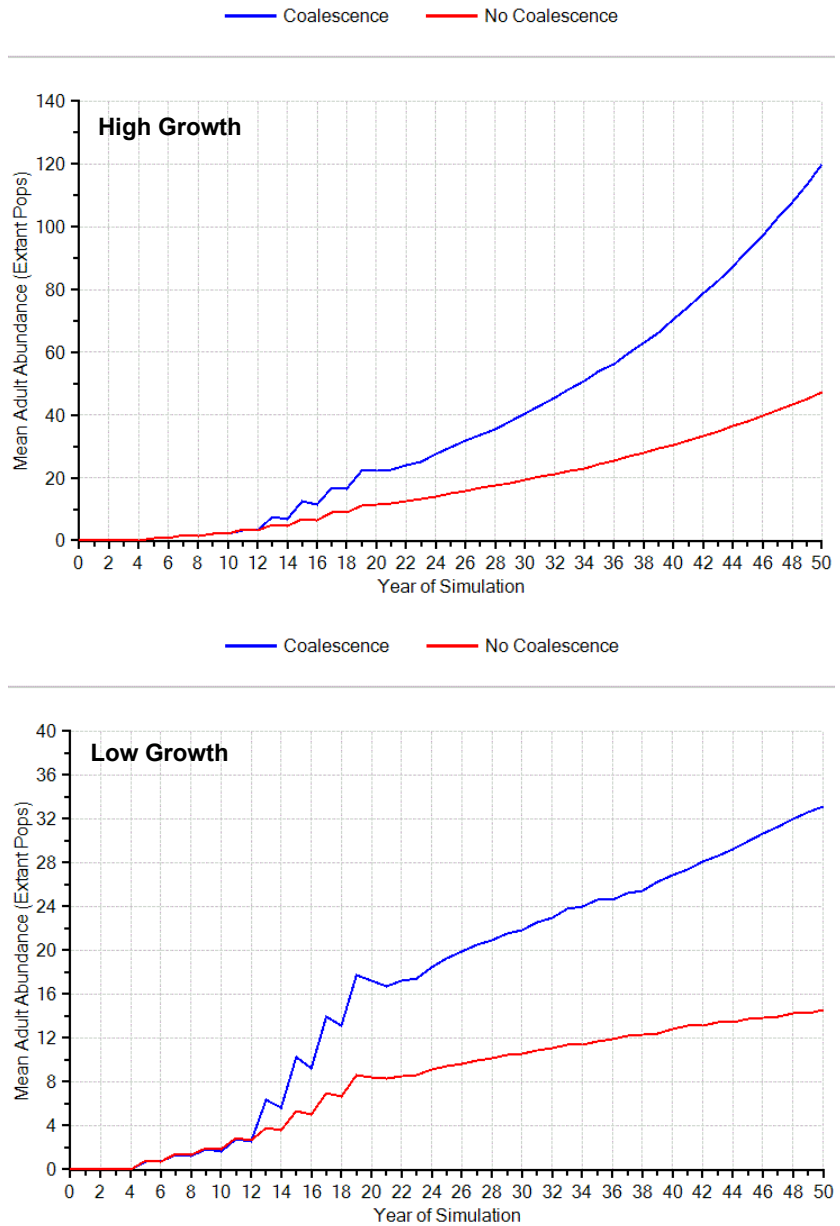


Figure 23. Mean abundance of adult bowmouth guitarfish in the wild release site under alternative assumptions of the initial wild population abundance. Simulations feature either the High Growth (top panel) or Low Growth (bottom panel) demographic profile. The release scenarios feature a 50% pup collection intensity in the aquarium population, a 15-year release program duration, and a release interval of two years. Calculation of mean abundance includes only those projection iterations that persist.

Figure 24. Mean abundance of adult bowmouth guitarfish in the wild release site and with or without the coalescence event among regional aquaria populations. Simulations feature either the High Growth (top panel) or Low Growth (bottom panel) demographic profile. The release scenarios feature a 50% pup collection intensity in the aquarium population, a 15-year release program duration, and a release interval of two years. Calculation of mean abundance includes only those projection iterations that persist.



The significant reduction in adult abundance observed in the “No Coalescence” scenarios can be at least partly explained by the reduced number of pups produced in the Asia regional aquarium population, which in this scenario remains effectively isolated from the other two regional populations in Europe and North America and, consequently, has lower levels of reproductive output (Figure 25). When the regional aquaria populations are able to freely exchange individuals (assumed to be in the form of gametes) to increase reproductive success, the number of pups available for collection from the Asia regional population can be as high as almost 20 animals on average following the coalescence event. If that coalescence event does not occur in the simulations, the number of pups collected reaches a sustained maximum of about 7-8 individuals. [Remember that these numbers represent about 50% of the total number of pups produced in the regional aquarium population, in accordance with the parameters that define the specific release program used in these scenarios.]

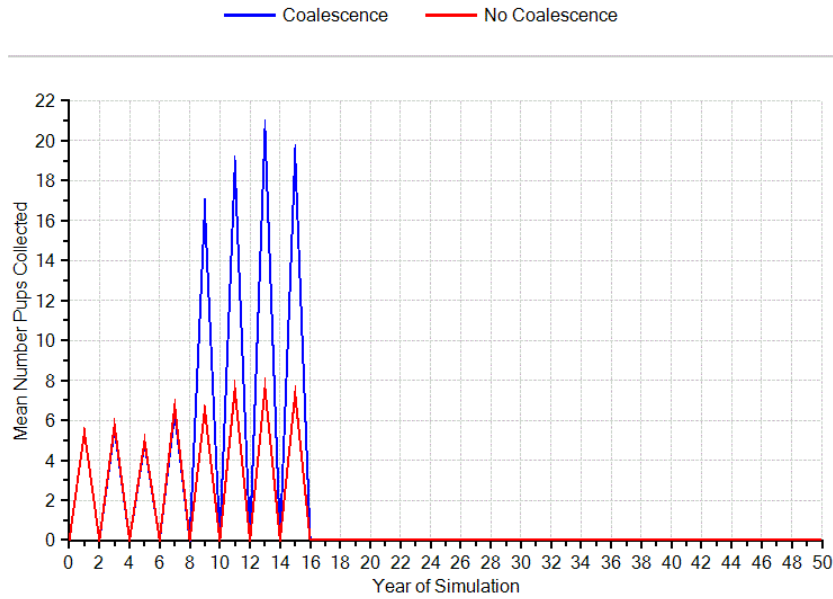
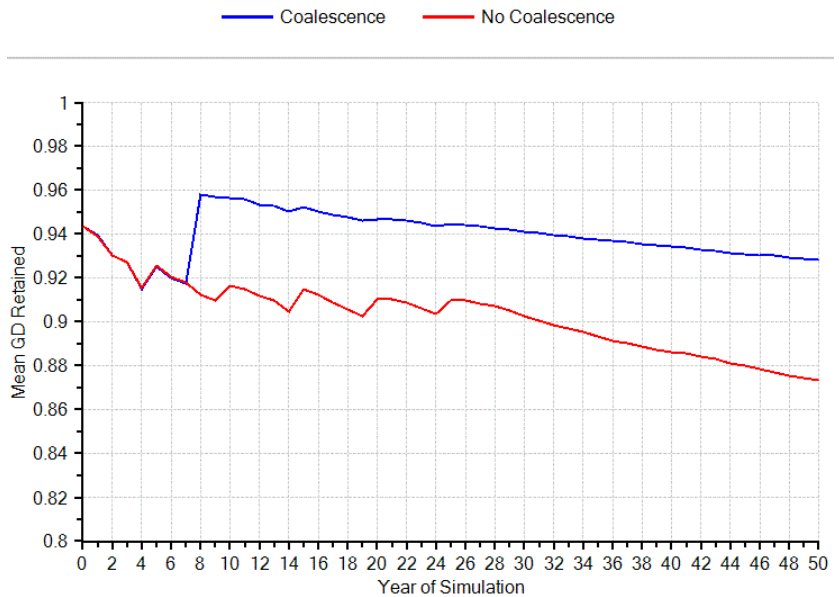


Figure 25. Mean number of bowmouth guitarfish pups collected from the Asia regional aquarium population and assuming either the presence or absence of the coalescence of the three regional aquaria populations into a single effectively global population. Scenarios feature intermediate levels of release intensity, duration and interval.

A key metric indicating the viability of an ex situ population is the amount of gene diversity retained in that population through time. If the Asia regional aquaria population remains genetic isolated from its European and North American counterparts, the population’s gene diversity does not experience the significant increase resulting from coalescence of all regional populations and instead continues to erode through time (Figure 26). The small “bumps” in gene diversity observed at five-year intervals up to year 25 through addition of wild-born animals rescued from bycatch are effective in reducing the overall loss of genetic diversity. Despite this addition of new genetic variants, gene diversity in this comparatively isolated population drops below 90% retention around year 30; in contrast, the scenario featuring regional population coalescence shows approximately 93% gene diversity retention across the 50-year duration of the simulation.

Figure 26. Mean gene diversity retained in the Asia regional aquarium population and assuming either the presence or absence of the coalescence of the three regional aquaria populations into a single effectively global population. Scenarios feature intermediate levels of release intensity, duration and interval.



Release scenarios: Summary of wild release site population performance

Figures 27 – 30 provide graphical summaries of the full range of release scenarios in order to more readily compare key model output metrics, namely the likelihood of persistence of a bowmouth guitarfish population in the wild release site at 50 years and the number of adults in that population if it were to persist. The following points highlight key insights from inspecting these results.

- The underlying population demographic profiles are significant factors influencing both the likelihood of population persistence and the adult abundance of persisting populations. While the set of persistence probability metrics across the release scenarios are certainly reduced under the Low Growth profile (e.g., Figure 27A vs. Figure 28A), the impact of reduced growth is considerably more pronounced when evaluating the associated abundance of adults among populations that persist for 50 years (e.g., Figure 29A vs. Figure 30A).
- As defined in this analysis, the El Niño climate event has a considerable impact on release population performance, particularly under the Low Growth demographic profile (Figure 28). The additional impact on adult abundance of persisting populations is pronounced under both population demographic profiles (Figures 29 and 30).
- The specific parameters governing the release program details appear to have a complex impact on the probability of successful population persistence across alternative population demographic profiles. For example, selecting a low proportion of aquarium-bred pups for release leads to a proportionally lower probability of population persistence in nearly all combinations of release program duration and release interval. The impact is most pronounced when the release program is short (e.g., 10 years) and the release interval is long (e.g., 3 years).
- The impacts of release program intensity, duration and interval on adult abundance among persisting populations are significant (e.g., Figure 29). A release program duration of 10 years results in a proportionally lower adult abundance than programs of longer duration, especially (and not surprisingly) when a larger proportion of pups is selected from the aquarium population for release.

In addition to these insights about the wild release site population, the results presented for the ex situ aquarium population suggest that the aquarium component can accommodate the removal of pups to support wild population viability. This conclusion is made on the basis of robust observed rates of population growth (e.g., Figures 9, 14 and 18) with no risk of population extirpation, and retention of at least 90% population gene diversity (e.g., Figures 11, 15 and 20) across the duration of the simulation. Of course, this observation is dependent on the fulfillment of at least two critical assumptions not yet realized in the current reality: ex situ pup mortality as observed in at least some of those institutions breeding bowmouth guitarfish must be significantly reduced to promote pup availability; and artificial reproduction techniques such as artificial insemination must be made feasible and available in order to effectively break down geographic barriers to promote breeding among a larger pool of adult females. If these hurdles can be overcome, it may be possible to produce the numbers of surviving pups for release that are necessary to stimulate wild population growth and persistence.

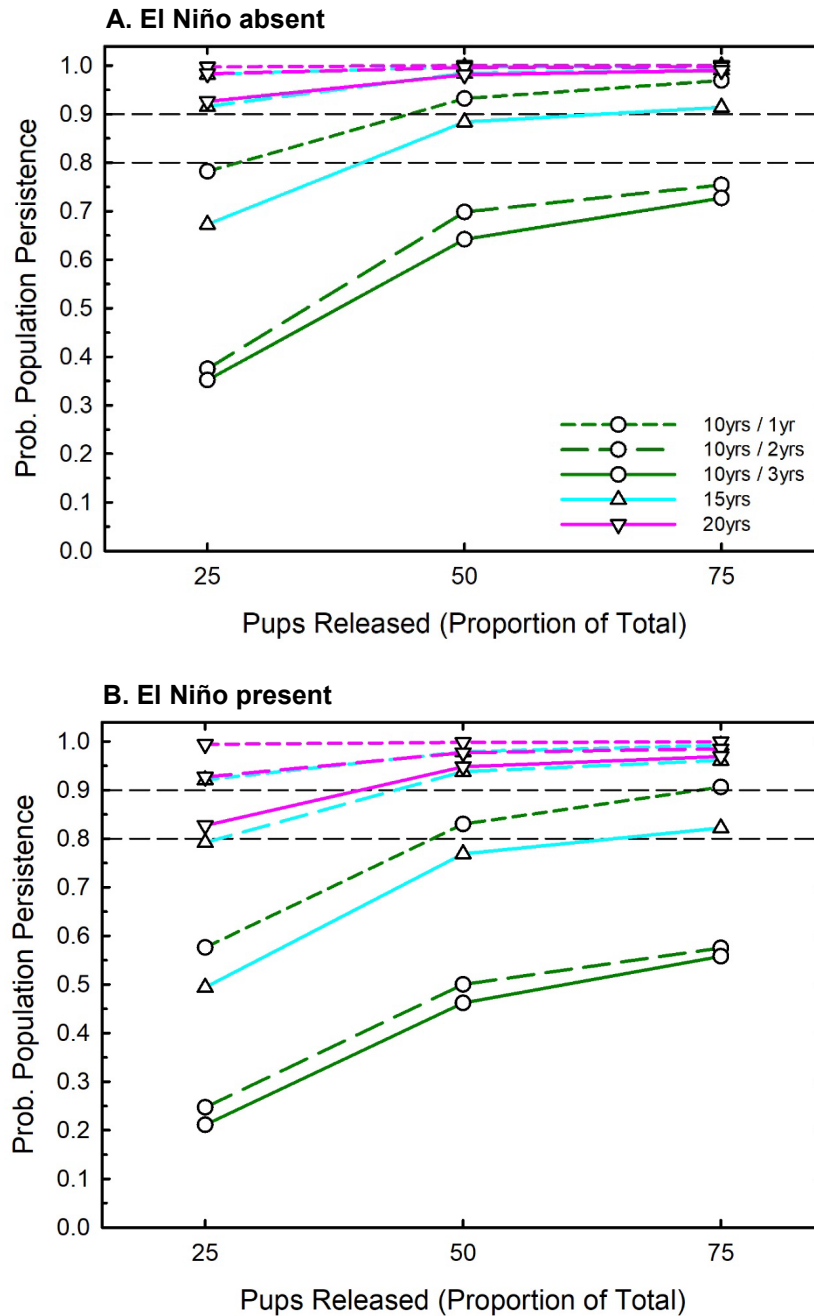


Figure 27. Probability of persistence after 50 years for simulated bowmouth guitarfish populations across the full range of release scenarios and as governed by the High Growth population demographic profile. Top panel (A), El Niño climate event is not included in the release scenarios; bottom panel (B), El Niño event is included. Values across the x-axis denote the release program intensity as defined by the proportion of all surviving pups produced in the aquarium population and translocated to the wild release site. Line colors refer to the release program duration (10, 15 or 20 years), while line type denotes the interval in years between pup releases (1, 2 or 3 years). Horizontal dashed lines identify example target thresholds for wild population persistence that might be representative of program success as agreed upon by program managers. See accompanying text for a more detailed description of model input parameters and model structure and function.

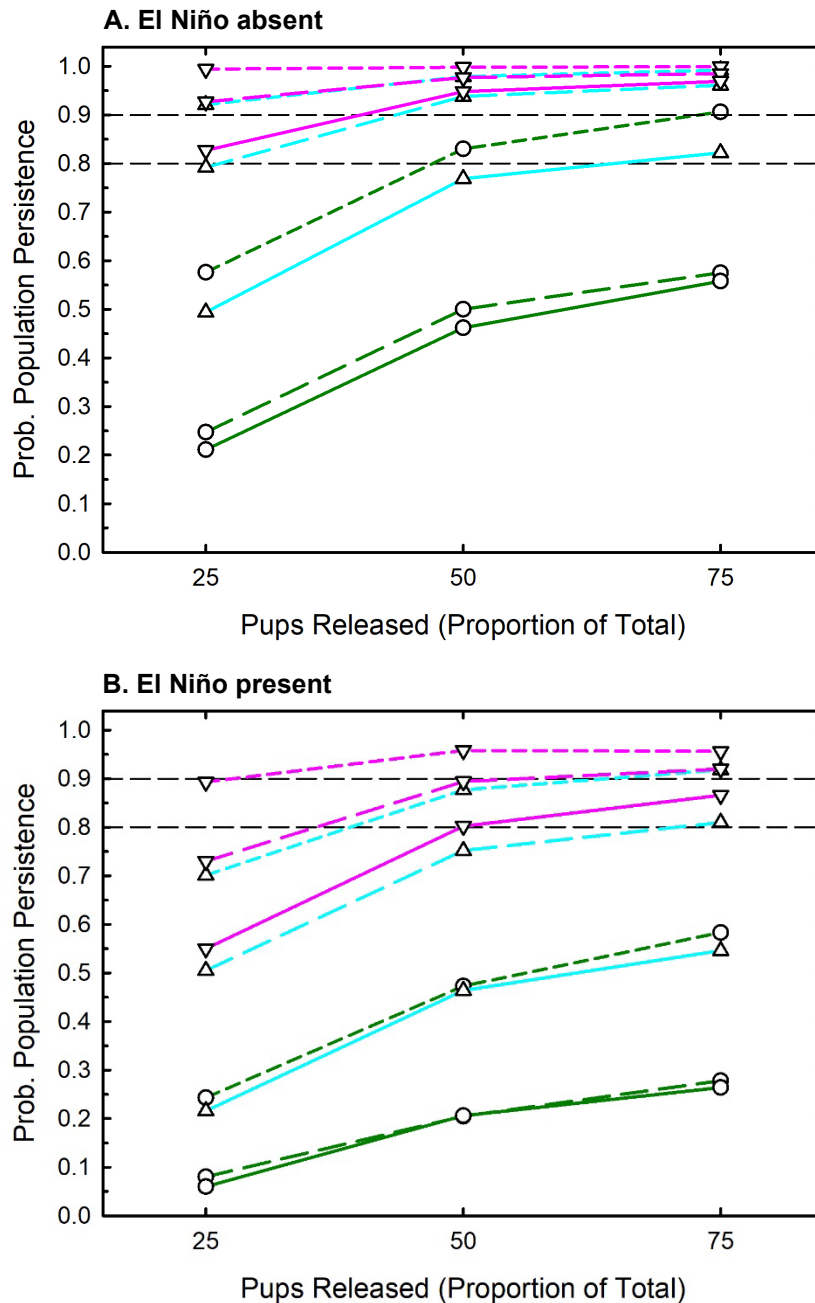


Figure 28. Probability of persistence after 50 years for simulated bowmouth guitarfish populations across the full range of release scenarios and as governed by the Low Growth population demographic profile. Top panel (A), El Niño climate event is not included in the release scenarios; bottom panel (B), El Niño event is included. Values across the x-axis denote the release program intensity as defined by the proportion of all surviving pups produced in the aquarium population and translocated to the wild release site. Line colors refer to the release program duration (10, 15 or 20 years), while line type denotes the interval in years between pup releases (1, 2 or 3 years). Horizontal dashed lines identify example target thresholds for wild population persistence that might be representative of program success as agreed upon by program managers. See accompanying text for a more detailed description of model input parameters and model structure and function.

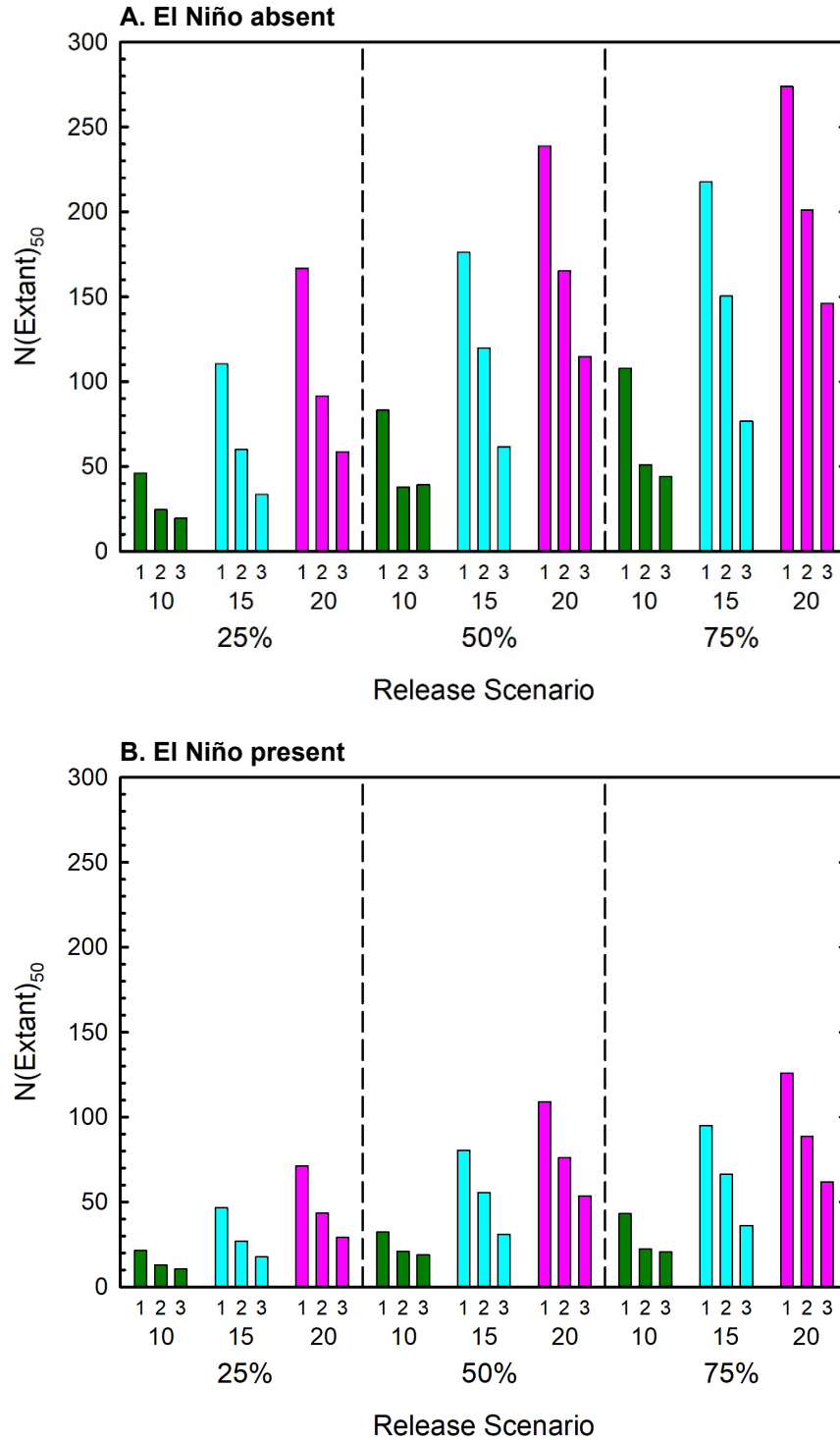


Figure 29. Mean adult population abundance after 50 years for simulated bowmouth guitarfish populations across the full range of release scenarios and as governed by the High Growth population demographic profile. Top panel (A), El Niño climate event is not included in the release scenarios; bottom panel (B), El Niño event is included. Values across the x-axis define the parameters of the range of release scenarios: release intensity, bottom row; release duration, middle row; release interval, top row. Bar colors correspond to pup release program durations as defined in Figure 27. Calculation of mean abundance includes only those projection iterations that persist. See accompanying text for a more detailed description of model input parameters and model structure and function.

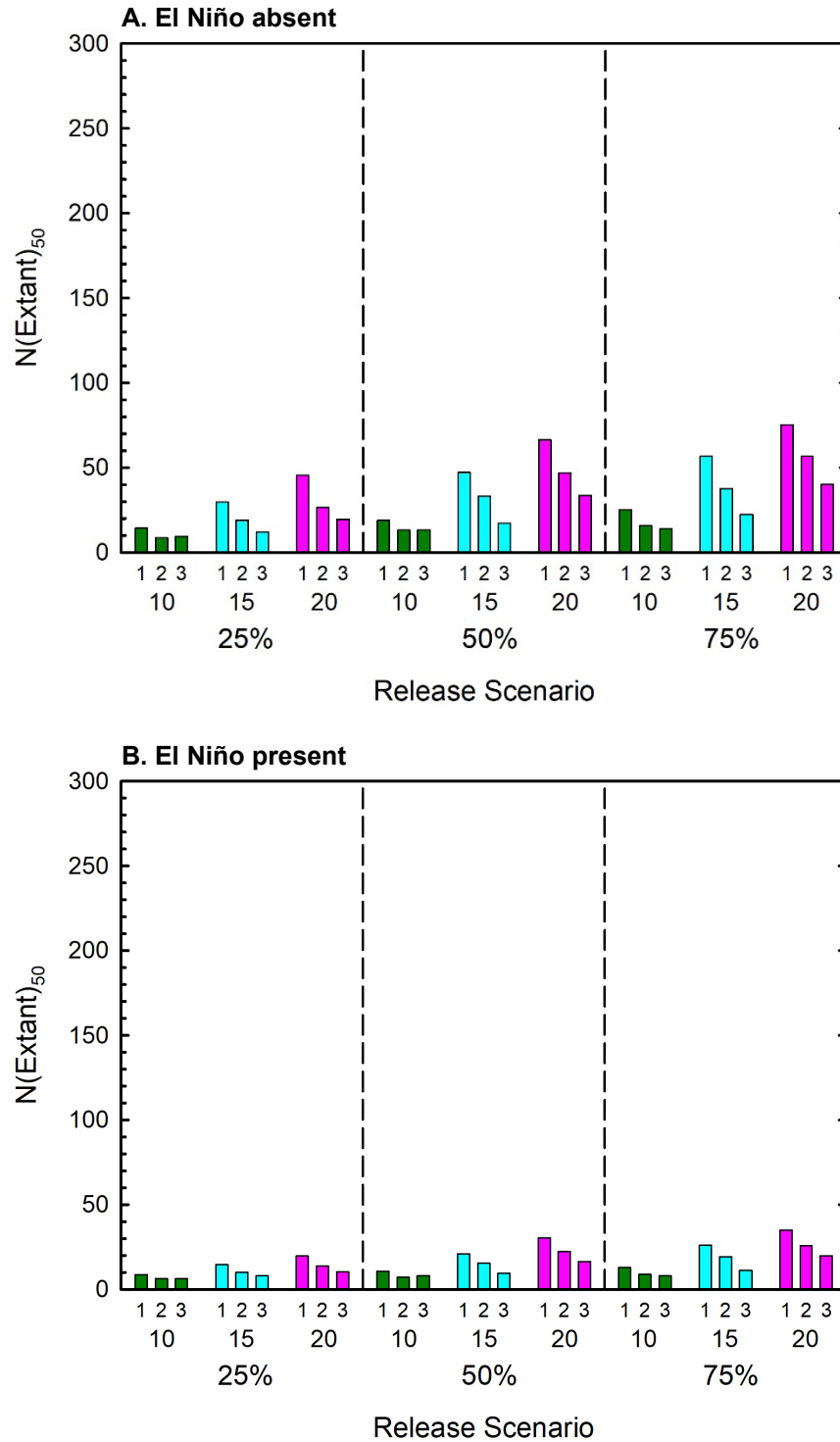


Figure 30. Mean adult population abundance after 50 years for simulated bowmouth guitarfish populations across the full range of release scenarios and as governed by the Low Growth population demographic profile. Top panel (A), El Niño climate event is not included in the release scenarios; bottom panel (B), El Niño event is included. Values across the x-axis define the parameters of the range of release scenarios: release intensity, bottom row; release duration, middle row; release interval, top row. Bar colors correspond to pup release program durations as defined in Figure 27. Calculation of mean abundance includes only those projection iterations that persist. See accompanying text for a more detailed description of model input parameters and model structure and function.

Discussion

The study of translocation biology has expanded significantly in recent decades as wildlife populations and their habitats become increasingly imperiled (e.g., Ewen et al. 2012). In particular, the evolution of analytical and simulation modeling tools has greatly improved the ability of wildlife biologists and managers to prospectively assess alternative options before embarking on costly and resource-intensive field projects (e.g., Osborne and Seddon 2012; Armstrong and Reynolds 2012; Converse et al. 2013; Gedir et al. 2013; Parlato and Armstrong 2018). As a modeling tool, population viability analysis stands out as an especially valuable framework for assembling demographic data on a focal species and its habitat, generating hypotheses about the system within which the translocation is taking place, and to objectively compare options for returning endangered species to their native habitats. It is in this spirit that the current PVA on the bowmouth guitarfish was designed and implemented.

For reintroductions to be successful, it is important to have secure habitats that represent “fertile ground” in which the individual “seeds” of translocation – the animals or plants selected for the specific purpose – can grow and prosper. In that context, this PVA attempts to evaluate both elements of the reintroduction equation – to provide guidance on the required ecological conditions in the destination habitat as well as the demographic composition of the individuals chosen for release. That said, analyses like this are especially challenging in that data describing the demographic characteristic of the species of interest in the habitat chosen for reintroduction are almost by definition unavailable. Results should therefore not be prescriptive but should instead help to identify broad thresholds for key program parameters that, when achieved, can improve opportunities for success.

Building on the information presented in the preceding paragraph, it is important for the population managers who will use this PVA to think carefully about a definition of success for this proposed translocation program. Perhaps the most recognizable metric of success might be the probability of persistence of the wild population that is receiving animals through the translocation efforts. The probability of exceeding a given threshold of persistence at a given point in the future can be readily obtained from the results of the models conducted in this analysis. Specifically, Figures 27 and 28 highlight persistence thresholds of 0.8 and 0.9 as examples of this type of success metric. Probabilities like these, particularly a 90% chance of population persistence, are often used in defining a demographic metric for viability (e.g., Doak et al. 2015; IUCN 2012). Additionally, genetic metrics of viability, most commonly defined as the retention of at least 90-95% of starting gene diversity over a given time period (typically 100 years), can be used in combination with demographic metrics to convey a more inclusive description of program success. These more quantitative definitions of a successful population management program can be stretched even further to include concepts of a population’s ecological functionality in the habitat – often leading to even larger threshold population sizes than would be defined by short-term viability alone (e.g., Redford et al. 2011). Management authorities can select the individual metrics that are most relevant for the species and its particular life history characteristics when identifying criteria for success.

In the case of the bowmouth guitarfish, a host of important uncertainties impede our ability at present to make specific predictions regarding how to best structure a reintroduction program. First, a specific release site has not yet been identified. There are a host of biological, ecological, economic, logistical, and regulatory factors that must be considered when choosing a site. From the standpoint of the risk analysis methodologies implemented here, identifying a site can provide a much more informed estimate of the ecological carrying capacity for bowmouth guitarfish that can reside there. Secondly, and even when a site has been identified, our ability to predict how the species will respond demographically after releases take place is challenging at best. Does the site feature abundant prey, microhabitats to support the needs of different life stages, and adequate protection from anthropogenic threats? It may be possible to provide qualitative answers to these questions, but how do those descriptive insights translate

into numerical inputs to predictive models of bowmouth guitarfish population dynamics? The strategy employed in this analysis – bracketing the range of potential environmental conditions as defined by alternative population growth rates – is the most realistic option for predicting how the species is likely to respond to relatively more favorable or unfavorable ecological conditions.

The standing abundance of bowmouth guitarfish in the release site of choice can have a substantial impact on the long-term success of any translocation program. In all but a few scenarios making up this analysis, it was assumed that the release site was effectively uninhabited by bowmouth guitarfish when release efforts were to begin. This assumption emerged because a specific candidate release site was not chosen while the PVA effort was underway. A set of prioritized biological, ecological, sociological, regulatory and political criteria were identified that were intended for use in choosing a short list of candidates. Deciding on one or two sites, however, requires critical knowledge on many parameters that collectively define the quality of that site. One such parameter is the existing population abundance at the potential site. Without that information, it becomes very challenging to develop reasonable assumptions about a resident population: the numerical abundance, age-sex structure, current demographic rates, and other population properties work together to characterize the potential growth dynamics of the population in that habitat. Because of these significant sources of uncertainty, the choice was made in this analysis to simply assume that the release site was effectively uninhabited. This assumption may very well turn out to be unrealistic as candidate sites are identified through additional analysis. However, this assumption has some value in focusing the assessment on the capacity of the ex situ source population to provide a satisfactory number of animals for release.

The analyses presented here indicate that even when the local environmental conditions provide opportunities for population growth, a very small “seed” population may not be able to benefit from those opportunities and may instead be impacted by the demographic and genetic instabilities inherent to the “extinction vortex” and may disappear. To overcome those destabilizing forces, reintroductions often require heavy efforts in the early stages to promote sustained population growth. The analyses described here suggest that moderate to high levels of release intensity, sustained with high frequency over extended timeframes, would likely be necessary to improve the chances for success.

Producing the desired number of pups for release means that the ex situ community must create favorable conditions for production of bowmouth guitarfish pups. Once again, the challenges of imperfect and inadequate information related to ex situ management of the species presents significant challenges at a critical moment. The PVA assumes that the causes of high pup mortality currently documented in the ex situ environment can be systematically studied and eliminated. Perhaps even more challenging is the effective genetic management of a species maintained across a host of institutions – many of whom care for a few animals or even single individuals – distributed around the world. The tactic adopted in this PVA, where aquaria distributed widely across one or more continents are grouped into regional populations, may at first seem rather abstract but might actually be a reasonably accurate depiction of the genetic structure of the global distribution of aquaria housing bowmouth guitarfish. In fact, treating a regional population spanning many institutions across a large continent like North America or Europe as one breeding population is likely an optimistic representation of that group’s capacity to retain high levels of genetic variation over time.

The “coalescence” of this global set of institutions – made possible through routine transfer of gametes rather than whole animals – into something approaching a single breeding population through adopting artificial insemination methods may be highly unrealistic in the short term, but prospects for its adoption are encouraging. The choice was made to explore this scenario as a framework for thinking about the implications of population genetic structure on the genetic and demographic viability of this critical population component. This is particularly relevant when, under the conditions defining this analysis, promoting persistence of a wild bowmouth guitarfish population may require the selection of at

least 50% of pups produced across a given set of institutions. Careful balancing among the goals of science-based management across the in situ – ex situ spectrum is required to achieve in situ population growth without imposing additional stress on the ex situ source.

Results from the initial set of analyses presented here suggest that the Asia regional component of the global aquarium community may be hard pressed to serve as the sole source of bowmouth guitarfish for successful reintroduction into the wild. This initial hypothesis was largely confirmed in a small set of additional exploratory analysis that assumed this global coalescence of individuals would not be possible. If coalescence does not occur, the existing regional group of aquaria in Asia may not be able to retain sufficient levels of gene diversity while also serving as the source of substantial numbers of pups for release to the wild. Importantly, this scenario also features occasional input of new wild animals to the regional aquaria population that were rescued from fishery bycatch. With these new animals come new genes that contribute to the overall levels of gene diversity that are monitored through analytical tools such as this PVA. If a specific genetic metric of viability is used as a component of program success, such as the 90% gene diversity threshold mentioned earlier, it may be necessary to link the Asia regional aquaria population to a larger group of managed animals that diversify the population with more founders and greater genetic diversity.

Alternatively, the community of institutions caring for the species would appear to significantly benefit from a sort of scientific globalization that moves beyond more traditional regional boundaries – an extension of the One Plan approach to integrated species management (Byers et al. 2013). This concept is certainly not new to those experts thinking about the scientific principles of ex situ management of endangered species (e.g., Lees and Wilcken 2009), but these principles can be operationalized at the individual species level to great effect.

The concepts, methods and mechanics defining this PVA will hopefully serve as a first step in continuing to refine evidence-based planning for bowmouth guitarfish both in the wild and in aquaria. A “Phase II” of this analysis might incorporate more information on the spatial ecology of the species, release site characteristics – for example, more refined estimates of habitat carrying capacity and appropriate population demographic growth profiles – and perhaps a more fine-tuned approach to integrated management of the species across the global array of aquaria, both existing institutions and perhaps additional institutions that may join the species management effort. The current analysis should be updated at regular intervals as new data and new thinking emerge to inform the ongoing process of improving the status of the species in the wild, using all available tools in our conservation arsenal.

Conclusions

If long-term success of a bowmouth guitarfish release program were defined as (1) probability of wild population persistence at 50 years ≥ 0.9 , and (2) wild population-level gene diversity retention $\geq 90\%$ at 50 years, the release program characteristics should include:

- Collect at least 50% of the pups produced from the regional aquaria population in the year of release;
- Conduct pup releases at least every other year for a minimum of 15 years (i.e., eight total release events), with annual releases recommended if using both demographic and genetic criteria for population success;
- Mean annual growth rate of the wild population over the course of the 50-year program should be no less than 5% (i.e., $\lambda \geq 1.05$).
- Ideally, ex situ management efforts should strive for at least some coalescence of regional aquaria populations in order to facilitate more effective reproductive output and enhanced rates of gene diversity retention.

A standing population of bowmouth guitarfish in the chosen release site can significantly enhance short-term growth potential in the wild population; consequently, key characteristics of the release program as outlined above could be relaxed to achieve program success. The degree to which release intensity can be modified is dependent on the demographic characteristics of the existing population at that site.

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Appendices

Appendix I.

Participants in the Bowmouth Guitarfish Workshop: May 2025, Singapore Oceanarium

Pink shaded cells: Individuals who participated virtually in the workshop

Gray shaded cells: PVA Model Development Team members

Bold: Individuals participating in at least one online PVA workshop session

Last Name	First Name	Affiliation	Country
Abel	Grant	Abel Conservation LLC / Singapore Oceanarium	SINGAPORE
Arey-Kent	Windy	SAFE Sharks & Rays	UNITED STATES
Baylina	Núria	Oceanario de Lisboa	PORTUGAL
Cahya Wardhana	Indra	Ministry of Marine Affairs and Fisheries	INDONESIA
Carlson	Paula	Dallas World Aquarium	UNITED STATES
Chansue	Dr Nantarika	Chulalongkorn University	THAILAND
Chiang	Riyar	Taiwan Fisheries Research Inst.; Save Our Seas Fdn.	TAIWAN
Choy	Christina	National Parks Board	SINGAPORE
Chua	Ming	Singapore Oceanarium	SINGAPORE
Clark-Shen	Dr Naomi	Rumah Foundation (local NGO in SG)	SINGAPORE
Coco	Chris	Georgia Aquarium	UNITED STATES
Curlee	Kevin	Disney Living Seas	UNITED STATES
Derbyshire	Nick	Singapore Oceanarium	SINGAPORE
Dudgeon	Dr Christine	University of Queensland	AUSTRALIA
Erdmann	Mark	Conservation International	AUSTRALIA
Dr Fahmi		National Research and Innovation Agency (BRIN)	INDONESIA
Fan	Fred	Fred Fan Aquatics	TAIWAN
Fatzinger	Hap	NC Aquariums/SAFE Shark and Ray	UNITED STATES
Feldheim	Dr. Kevin	Field Museum	UNITED STATES
Fernando	Daniel	Blue Resources Trust	SRI LANKA
Fong	Jenny	Singapore Oceanarium	SINGAPORE
Ford	Johnny	Shedd Aquarium	UNITED STATES
Grant	Dr. Michael	James Cook University	AUSTRALIA
Gupta	Trisha	Zoological Society of London	UNITED KINGDOM
Haetrakul	Dr Thanida	Chulalongkorn University, Thailand	THAILAND
Hana	Jolene	Newport Aquarium	UNITED STATES
Hartoko	Agus	Diponegoro University	INDONESIA
Hazeres	Jennifer	Newport Aquarium	UNITED STATES
Heatubun	Prof Charlie	Indonesian government	INDONESIA
Hoopes	Dr. Lisa	Georgia Aquarium	UNITED STATES
Hsu	Hua-Hsun	Taiwan Fisheries Research Institute	TAIWAN
Hsu	Tsui-Chun	National Museum of Marine Science & Technology	TAIWAN
Humble	Dr. Emily	University of Edinburgh	UNITED KINGDOM

Last Name	First Name	Affiliation	Country
Hutchinson	Neil	James Cook University Singapore	SINGAPORE
Ichida	Nesha	Thrive Conservation	INDONESIA
Ichsan	Muhammad	University of the Sunshine Coast; Save Our Seas Fdn.	AUSTRALIA
Jabado	Dr. Rima	IUCN SSC Shark Specialist Group	UNITED ARAB EMIRATES
Kessel	Dr. Steve	Shedd Aquarium	UNITED STATES
Krajangdara	Tassapon	IUCN Species Survival Commission (SSC)	THAILAND
Kurniawan	Ardiansyah	Universitas Bangka Belitung	INDONESIA
Kwan	Kenneth	Bali Safari & Marine Park	INDONESIA
Kwok	Ashley	Ocean Park Hong Kong Corporation, HKSAR	HONG KONG
Lopez	Alfonso	Singapore Oceanarium	SINGAPORE
Lotter	Paul	Atlantis the Palm	UNITED ARAB EMIRATES
Marikan	Salam	Singapore Oceanarium	SINGAPORE
Martelli	Dr Paolo	Ocean Park Hong Kong Corporation, HKSAR	HONG KONG
Matsumoto	Rui	Okinawa Churaumi Foundation	JAPAN
McCracken	Robbie	Merlin/Sea Life Sydney	AUSTRALIA
Mewhirter	Hannah	Seattle Aquarium	UNITED STATES
Miller	Dr. Phil	Conservation Planning Specialist Group (IUCN SSC)	UNITED STATES
Mylniczzenko	Dr. Natalie	Disney Living Seas	UNITED STATES
Penfold	Dr. Linda	SEZARC	UNITED STATES
Pham	Nancy	SEZARC	UNITED STATES
Pollom	Riley	Resorts World Sentosa	SINGAPORE
Price	Mike	Sea World Yas Island, Abu Dhabi	UNITED ARAB EMIRATES
Purushottama	G.B.	Central Marine Fisheries Research Institute	INDIA
Rigby	Dr. Cassie	James Cook University, Australia	AUSTRALIA
Rookkachard	Patinan	Bali Safari & Marine Park	INDONESIA
Sim	Andrew	Seattle Aquarium	UNITED STATES
Simmons	Laura	Merlin/Sea Life Sydney	AUSTRALIA
Simpfendorfer	Prof. Colin	James Cook University/Hobart Uni	AUSTRALIA
Sloan	Peggy	Shedd Aquarium	UNITED STATES
Su	Nan Jay	National Ocean Taiwan University	TAIWAN
Tanna	Akshay	Blue Resources Trust	SRI LANKA
Taurá	Carlos	Oceanographic Valencia	SPAIN
Torno	Chris	Singapore Oceanarium	SINGAPORE
Weng	Dr. Kevin	Virginia Institute of Marine Science	UNITED STATES
Winkler	Abigail	Shedd Aquarium	UNITED STATES

Appendix II.
 Aquarium Population Studbook File

- This file includes only those bowmouth guitarfish that are known to have been caught in the appropriate Southeast Asian region considered suitable for release of pups to establish a new population.
- Individuals with ID highlighted in tan are considered founders as they are known to be born or conceived in the wild. Individuals with ID = WILDx are assumed to be unrelated founders that produced known individuals in the studbook.
- All founders are considered to be unrelated to one another.
- Age is specified in years.
- Alive: 0 = Dead; 1 = Alive. Age of dead individuals is of no concern in the calculations.

Rhina ancylostomus as of 07/07/2025

Regions: 1=Wild; 2=Eastern Indian Ocean(EIO)-Asia; 3=EIO-Europe; 4=EIO-US

ID	Sire	Dam	Sex	Age	Alive	Population	Institution
WILD1	WILD	WILD	M	100	0	1	
WILD2	WILD	WILD	F	100	0	1	
WILD3	WILD	WILD	M	100	0	1	
WILD4	WILD	WILD	M	100	0	1	
2	WILD	WILD	M	20	1	4	Newport Aquarium
4	WILD	WILD	F	17	1	4	Shark Reef at Mandalay Bay
9	WILD	WILD	M	18	1	4	Georgia Aquarium
10	WILD	WILD	F	18	1	4	Georgia Aquarium
11	WILD	WILD	F	11	1	4	Georgia Aquarium
32	WILD1	69	M	8	1	2	Hong Kong Ocean Park
33	WILD1	69	F	8	1	2	Hong Kong Ocean Park
53	WILD3	WILD2	F	3	1	4	Seattle Aquarium
54	WILD3	WILD2	F	3	1	4	Shedd Aquarium
55	WILD3	WILD2	F	3	1	4	Newport Aquarium
56	WILD3	WILD2	F	3	1	4	Shedd Aquarium
57	WILD3	WILD2	M	3	1	4	Georgia Aquarium
58	WILD3	WILD2	F	3	1	4	Georgia Aquarium
59	WILD3	WILD2	M	3	1	4	Georgia Aquarium
61	WILD3	WILD2	M	3	1	4	The Seas with Nemo and Friends
68	WILD	WILD	F	21	1	2	Singapore Oceanarium
69	WILD	WILD	F	21	1	2	Singapore Oceanarium
70	WILD	WILD	F	20	1	2	Singapore Oceanarium
71	WILD	WILD	F	20	1	2	Singapore Oceanarium
72	WILD	WILD	M	20	1	2	Singapore Oceanarium
73	WILD	WILD	M	20	1	2	Singapore Oceanarium
74	72	69	M	9	1	2	Singapore Oceanarium
75	WILD	WILD	F	7	1	2	Singapore Oceanarium
82	73	68	F	8	1	2	Tokyo Sea Life Park
83	73	68	M	8	1	2	Tokyo Sea Life Park

ID	Sire	Dam	Sex	Age	Alive	Population	Institution
85	73	69	F	8	1	2	SEA LIFE Bangkok
86	73	69	F	8	1	2	SEA LIFE Bangkok
93	WILD	WILD	M	5	1	2	Hong Kong Ocean Park
94	WILD	WILD	F	3	1	2	Hong Kong Ocean Park
95	WILD	WILD	F	15	1	3	SEA LIFE Oberhausen
97	WILD	WILD	M	7	1	3	Acuario Poema del Mar
98	WILD	WILD	F	8	1	3	Acuario Poema del Mar
99	WILD	WILD	F	11	1	3	SEA LIFE Birmingham
100	WILD	WILD	F	10	1	3	National Aquarium of Denmark
101	WILD	WILD	M	11	1	3	National Aquarium of Denmark
102	WILD	WILD	F	14	1	3	SEA LIFE London
103	WILD	WILD	M	1	1	2	Marine Safari Bali
104	WILD	WILD	F	1	1	2	Marine Safari Bali
105	WILD	WILD	M	1	1	2	Marine Safari Bali
107	WILD4	115	M	1	1	3	Royal Burgers' Zoo
108	WILD4	115	M	1	1	3	Oceanario de Lisboa
109	WILD4	115	F	1	1	3	Oceanografic Valencia
110	WILD4	115	F	1	1	3	Oceanografic Valencia
111	WILD4	115	M	1	1	3	Nausicaa Centre National De La Mer
113	WILD	WILD	M	2	1	2	Singapore Oceanarium
114	WILD	WILD	F	2	1	2	Singapore Oceanarium
115	WILD	WILD	F	8	1	2	Okinawa Churaumi Aquarium
116	WILD4	115	M	1	1	2	Okinawa Churaumi Aquarium
117	WILD4	115	F	1	1	2	Okinawa Churaumi Aquarium
126	74	69	M	1	1	2	Singapore Oceanarium
127	74	69	M	1	1	2	Singapore Oceanarium
128	74	69	F	1	1	2	Singapore Oceanarium
129	74	69	F	1	1	2	Singapore Oceanarium
130	9	11	M	1	1	4	Georgia Aquarium
131	9	11	F	1	1	4	Georgia Aquarium
132	9	11	M	1	1	4	Georgia Aquarium
133	9	11	M	1	1	4	Georgia Aquarium
134	9	11	F	1	1	4	Georgia Aquarium
135	9	11	M	1	1	4	Georgia Aquarium
136	9	11	F	1	1	4	Georgia Aquarium
137	9	11	M	1	1	4	Georgia Aquarium

Appendix III.
Selected Features of PVA Scenarios

A. Identification of populations. Note the use of a “Holding” population, a mandatory component of the Translocation module in Vortex. The Holding population is unoccupied after the release of pups, with no reproduction or survival allowed there.

Number of populations _____

	Population 1	Population 2	Population 3	Population 4	Population 5	Population 6
Name	Release Site	EIO_Aquaria-Asi	EIO_Aquaria-Eur	EIO_Aquaria-NA	WildSource	Holding

B. Event sequence for each scenario. Note the Dispersal event, which allows for the occasional introduction of adults from the Wild Source population, taking place at the beginning of the annual cycle. This allows for the immediate availability of those animals for breeding if possible.

- EV
 - Disperse
 - Breed
 - ISUpdate
 - Mortality
 - Harvest
 - Supplement
 - Age
 - rCalc
 - Ktruncation
 - PSUpdate
 - Census

C. State Variables. Each of the Population State Variables is created to generate custom output for testing overall model function. The Individual State Variable “Origin” tracks an individual’s birthplace so that animals of the appropriate origin – Aquarium or Wild Source – are translocated to the proper destination (Wild Release Site of Aquarium, respectively).

Select for which population you want to set functions:

Population State Variables _____

Variable	Label	Initialization function	Transition function
PS1	Litters		=BROODS
PS2	Offspring		=PROGENY/BROODS
PS3	Adults		98 =F+M
PS4	Collected		=HARVESTS
PS5	Released		=SUPPLEMENTS
PS6	Pups		=PROGENY

Individual State Variables

Variable	Label	Initialization function	Birth function	Transition function
IS1	Origin	=P	=P	=IS1

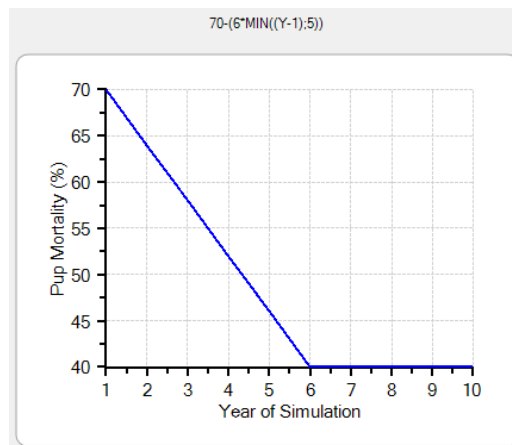
D. Dispersal mechanic. In model year 8, all animals from the Europe and North America regional aquaria populations are “moved” to the Asia regional aquarium population. This crudely simulates the integration of the regional populations into a global population following the adoption of artificial reproduction methods that greatly facilitate global transport of gametes (sperm) to largely remove geographic boundaries to breeding.

Enter percents of individuals in each age-sex class that disperse between each pair of populations each year; Row = Source; Column = Recipient population

Release Site	Release Site	EIO_Aquaria-Asia	EIO_Aquaria-Eur	EIO_Aquaria-NA	WildSource	Holding
Release Site	100	0	0	0	0	0
EIO_Aquaria-Asia	0	100	0	0	0	0
EIO_Aquaria-Eur	0	=(Y=8)*100		0	0	0
EIO_Aquaria-NAmer	0	=(Y=8)*100	0		0	0
WildSource	0	0	0	0	100	0
Holding	0	0	0	0	0	100

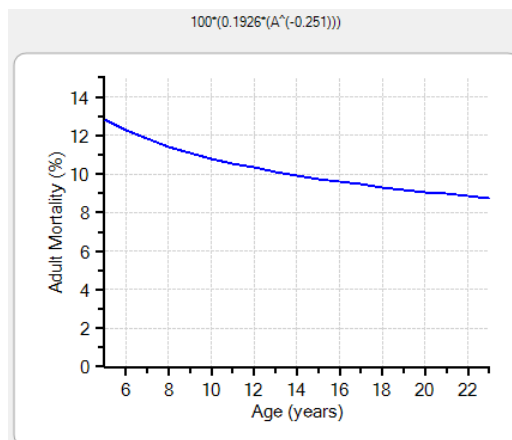
E. Aquarium population pup mortality. The function below generates a steady decline in pup mortality from 70% to 40% over a 5-year period. The rate is set to 70% for model year 1 and, after five years, declines to its low end in model year 6.

$$\text{Rate} = 70 - (6 * (\text{MIN}(Y-1); 5))$$



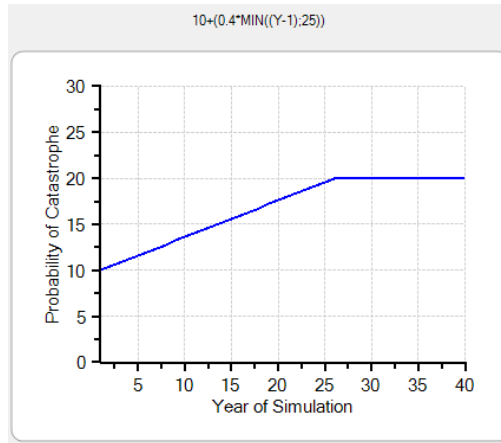
F. Adult mortality in the wild release site. The function below, derived from the Peterson – Wroblewski mortality estimator methodology, generates an age-specific mortality curve across the adult life stage.

$$\text{Rate} = 100 * (0.1926 * (A^{-0.251}))$$



G. Specification of El Niño catastrophic event. The function below describes an annual event frequency that begins at 10% in model year 1 and increase to 20% after 25 years.

$$\text{Rate} = 10 + (0.4 * (\text{MIN}(Y-1); 25))$$

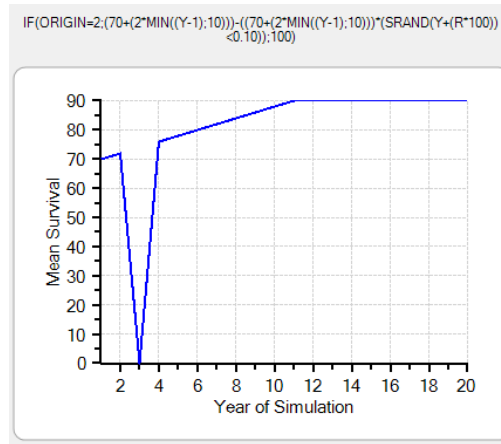


H. Specification of population carrying capacity (K). The value for K is estimated assuming that each qualifying institution (known or suspected to care for animals originating in Asian waters) can maintain a maximum of four adults. The function for the Asia population simulates the “expansion” of that population following the “dispersal” of all the animals from the other regional aquaria into what becomes a global breeding population in model year 8.

	Release Site	EIO_Aquaria-Asia	EIO_Aquaria-Eur	EIO_Aquaria-NA	WildSource	Holding
Carrying Capacity (K)	425	$= (4 * 15) + (Y > 7) * (4 * 17)$	$= 4 * 9$	$= 4 * 8$	425	0
SD in K due to EV	0	0	0	0	0	0

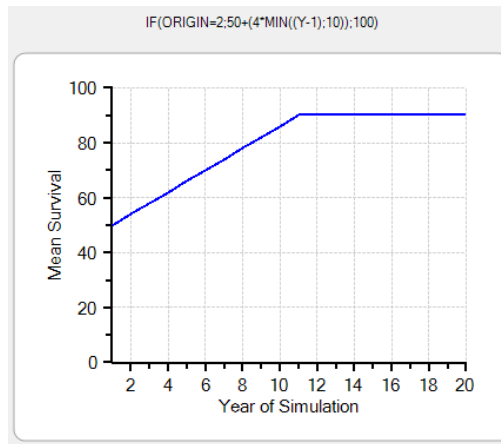
- I. Pup release mechanic: Collection, transport and holding. The function component in red below specifies that individuals whose Origin is the Asia regional aquarium population (Global population beginning in model year 8) will originally experience a 70% survival rate during transport and holding before, and that survival rate will gradually increase to 90% over the next 10 years. The component in blue specifies the probability of a “nursery failure” catastrophe in which the mortality becomes 100% during the holding phase of the planned translocation. This failure is set to occur on average once every 10 years. The combined dynamics of this survival phase is given in the figure below. Finally, there is a 100% survival (black text at the far right) of individuals transferred into the Asia (Global) aquarium population from the Wild Source population, simulating introduction of individuals from local fisheries bycatch.

$$=IF(ORIGIN=2; (70+(2*MIN((Y-1);10))) - ((70+(2*MIN((Y-1);10)))*(SRAND(Y+(R*100))<0.10));100)$$



- J. Pup release mechanic: Release to Wild Site. The first function below defines post-release survival of pups in a manner similar to the transport and holding mechanic discussed above. In model year 1, the survival of pups from release to the time of population census immediately before the next annual timestep begins at 50% and gradually increases to 90% in ten years.

$$=IF(ORIGIN=2; 50+(4*MIN((Y-1);10));100)$$



An additional function governing this mechanic specifies the destination of specific individuals based on their population or origin. Pups collected from the aquarium population (ORIGIN=2) can only go to the Wild Release Site (variable T = destination population = 1), while animals collected via bycatch in the Wild Source (ORIGIN = 5) are moved to the regional aquarium population (T = 2).

$$= ((ORIGIN=2) AND (T=1)) OR ((ORIGIN=5) AND (T=2))$$

Appendix IV. Detailed Release Scenario Results

Tables IV.1 through IV.4 on the following pages give a more complete listing of the results from the 108 release scenarios that were run as part of the bowmouth guitarfish PVA. The scenarios are grouped into four tables according to the underlying demographic growth profile assumed to be operating in the wild release site.

Column headings are defined as follows:

- % Pups: Percentage of surviving pups produced in the aquarium population that are targeted for collection as part of the release program.
- Duration: Total number of years comprising the pup release program.
- Interval: Number of years between each release event.
- Population: Identity of the population for which output data are presented.
- r(s): Mean stochastic population growth rate, calculated as the mean of $\ln(N_{t+1} / N_t)$ for $t = 0 - 49$.
- SD(r): Standard deviation in stochastic growth $r(s)$.
- Pr(Persist): The probability of population persistence in the wild release site or the aquarium population at the end of the simulation, defined simply as $1 - (\text{probability of population extinction})$ at year 50.
- N(Ext): Mean size of the population at the end of the 50-year simulation, calculated using only those iterations that do not decline to extinction.
- SD(N): Standard deviation of the mean extant population abundance at year 50.
- GD: Mean proportion of starting gene diversity retained within a population at the end of the simulation.
- SD(GD): Standard deviation of mean gene diversity at year 50.
- Adults: Mean number of adults in a population at the end of the 50-year simulation, calculated using only those iterations that do not decline to extinction.
- SD(Ads): Standard deviation of mean number of adults at year 50.

Table IV.1: High Growth

Release Mechanics												
%Pups	Duration	Interval	Population	r(s)	SD(r)	Pr(Persist)	N(Ext)	SD(N)	GD	SD(GD)	Adults	SD(Ads)
25	10	1	Release Site	0.053	0.239	0.782	99.5	102.9	0.771	0.116	46.0	44.9
			Aquaria	0.059	0.184	1	297.0	55.4	0.935	0.019	119.3	18.6
		2	Release Site	0.019	0.293	0.375	50.3	58.9	0.689	0.139	24.6	26.3
			Aquaria	0.061	0.188	1	303.3	50.1	0.937	0.017	120.8	15.3
		3	Release Site	0.009	0.297	0.352	39.8	42.6	0.673	0.145	19.5	19.2
			Aquaria	0.061	0.184	1	303.0	50.1	0.938	0.014	121.2	15.4
15	1	1	Release Site	0.084	0.199	0.982	252.2	198.3	0.873	0.066	110.4	82.7
			Aquaria	0.054	0.185	1	283.0	66.7	0.932	0.024	114.1	23.4
		2	Release Site	0.060	0.267	0.916	132.4	118.0	0.824	0.090	60.0	51.2
			Aquaria	0.058	0.188	1	294.4	55.5	0.935	0.017	118.3	18.9
		3	Release Site	0.030	0.292	0.673	70.8	73.0	0.742	0.141	33.4	32.7
			Aquaria	0.060	0.186	1	302.2	50.8	0.938	0.015	120.6	16.1
20	1	1	Release Site	0.097	0.187	0.997	387.3	248.2	0.909	0.034	166.8	102.4
			Aquaria	0.049	0.191	0.999	264.4	78.0	0.928	0.023	107.1	28.8
		2	Release Site	0.075	0.257	0.983	209.3	165.8	0.868	0.067	91.5	69.9
			Aquaria	0.056	0.188	1	290.3	58.6	0.935	0.017	116.6	20.2
		3	Release Site	0.055	0.288	0.926	131.3	119.0	0.830	0.095	58.7	50.5
			Aquaria	0.058	0.188	1	297.3	53.2	0.936	0.016	119.5	17.4
50	10	1	Release Site	0.069	0.223	0.932	185.2	163.6	0.838	0.083	83.2	70.4
			Aquaria	0.054	0.204	0.999	282.4	69.2	0.930	0.019	113.7	24.6
		2	Release Site	0.036	0.281	0.698	80.8	83.0	0.744	0.140	37.9	36.6
			Aquaria	0.059	0.210	1	297.8	53.5	0.935	0.016	119.2	17.4
		3	Release Site	0.029	0.295	0.642	84.2	79.6	0.757	0.127	39.2	35.3
			Aquaria	0.060	0.206	1	298.9	53.2	0.936	0.016	119.7	17.6
15	1	1	Release Site	0.092	0.199	0.997	408.8	255.1	0.904	0.045	176.2	105.5
			Aquaria	0.044	0.210	1	234.8	90.6	0.917	0.028	95.3	34.0
		2	Release Site	0.075	0.271	0.984	274.7	209.3	0.876	0.074	120.0	88.4
			Aquaria	0.051	0.217	1	272.9	71.3	0.928	0.021	110.6	25.9

Release Mechanics												
%Pups	Duration	Interval	Population	r(s)	SD(r)	Pr(Persist)	N(Ext)	SD(N)	GD	SD(GD)	Adults	SD(Ads)
50	15	3	Release Site	0.047	0.292	0.884	135.0	134.5	0.816	0.097	61.5	57.7
			Aquaria	0.057	0.208	1	293.5	56.8	0.935	0.016	117.7	19.3
	20	1	Release Site	0.102	0.195	1	558.8	285.4	0.924	0.027	238.8	116.7
			Aquaria	0.034	0.214	0.993	184.1	95.2	0.904	0.039	75.7	36.8
		2	Release Site	0.085	0.272	0.996	383.9	243.5	0.906	0.042	165.3	100.8
			Aquaria	0.047	0.222	1	256.2	79.7	0.925	0.026	104.1	29.8
		3	Release Site	0.069	0.294	0.981	263.3	197.0	0.884	0.064	114.8	82.6
			Aquaria	0.054	0.213	1	284.2	66.7	0.932	0.019	114.4	23.5
75	10	1	Release Site	0.074	0.220	0.969	243.3	206.4	0.854	0.075	107.8	86.9
			Aquaria	0.050	0.226	1	264.4	77.3	0.923	0.025	107.5	28.5
		2	Release Site	0.040	0.279	0.754	111.0	121.6	0.775	0.118	51.0	52.9
			Aquaria	0.057	0.228	1	294.2	55.4	0.934	0.016	118.6	18.1
		3	Release Site	0.032	0.293	0.727	95.9	98.4	0.770	0.112	44.1	41.9
			Aquaria	0.059	0.221	1	296.3	56.8	0.935	0.017	118.7	18.8
15		1	Release Site	0.096	0.202	0.999	507.6	287.4	0.914	0.040	217.7	118.8
			Aquaria	0.035	0.235	0.993	189.1	97.8	0.899	0.045	77.2	37.9
		2	Release Site	0.078	0.272	0.991	344.4	243.8	0.891	0.064	150.3	102.5
			Aquaria	0.049	0.239	1	260.6	80.2	0.925	0.023	105.4	29.8
		3	Release Site	0.052	0.297	0.914	172.4	160.8	0.834	0.088	76.6	68.4
			Aquaria	0.055	0.221	1	288.8	62.0	0.933	0.017	116.2	21.5
20		1	Release Site	0.103	0.196	1	642.0	290.7	0.928	0.023	273.9	118.7
			Aquaria	0.022	0.245	0.976	117.2	77.9	0.869	0.062	48.6	31.0
		2	Release Site	0.088	0.271	0.997	467.1	274.8	0.913	0.045	201.0	114.1
			Aquaria	0.043	0.248	0.998	230.3	90.3	0.915	0.032	93.6	34.5
		3	Release Site	0.074	0.302	0.99	338.3	241.3	0.897	0.050	146.2	100.6
			Aquaria	0.051	0.231	1	274.1	72.7	0.929	0.021	110.6	26.6

Table IV.2: High Growth – El Niño

Release Mechanics												
%Pups	Duration	Interval	Population	r(s)	SD(r)	Pr(Persist)	N(Ext)	SD(N)	GD	SD(GD)	Adults	SD(Ads)
25	10	1	Release Site	0.032	0.273	0.576	45.1	54.0	0.731	0.118	21.4	23.3
			Aquaria	0.058	0.187	1	294.4	58.0	0.935	0.016	118.6	19.6
		2	Release Site	0.002	0.319	0.247	25.3	25.7	0.656	0.157	13.0	12.1
			Aquaria	0.061	0.186	1	304.0	50.5	0.937	0.016	121.1	15.0
		3	Release Site	-0.010	0.327	0.211	20.6	18.9	0.649	0.153	10.5	9.1
			Aquaria	0.061	0.185	1	302.3	49.8	0.937	0.016	121.1	15.8
15		1	Release Site	0.060	0.222	0.921	103.5	93.8	0.837	0.086	46.7	39.9
			Aquaria	0.054	0.184	1	283.4	68.1	0.931	0.020	113.7	24.3
		2	Release Site	0.035	0.290	0.792	58.2	60.8	0.785	0.104	27.0	26.2
			Aquaria	0.058	0.189	1	295.7	55.8	0.935	0.018	118.7	18.8
		3	Release Site	0.007	0.320	0.494	36.3	40.3	0.710	0.153	17.7	18.2
			Aquaria	0.061	0.185	1	300.8	50.8	0.938	0.014	120.7	15.6
20		1	Release Site	0.075	0.206	0.994	161.7	132.6	0.883	0.058	71.4	55.5
			Aquaria	0.049	0.190	1	263.0	83.7	0.927	0.026	105.7	30.4
		2	Release Site	0.053	0.278	0.927	96.5	84.2	0.839	0.086	43.5	36.5
			Aquaria	0.057	0.189	1	292.3	62.1	0.934	0.023	117.2	20.6
		3	Release Site	0.032	0.309	0.827	62.2	57.1	0.806	0.100	29.1	24.7
			Aquaria	0.058	0.188	1	298.6	54.2	0.936	0.015	119.4	17.0
50	10	1	Release Site	0.044	0.251	0.83	69.2	67.5	0.790	0.104	32.3	29.8
			Aquaria	0.053	0.202	1	279.6	70.1	0.929	0.020	112.8	24.9
		2	Release Site	0.014	0.311	0.5	43.0	45.6	0.730	0.127	20.9	20.6
			Aquaria	0.059	0.211	1	297.4	54.0	0.935	0.016	119.3	17.8
		3	Release Site	0.003	0.320	0.462	38.5	40.6	0.704	0.143	18.8	18.5
			Aquaria	0.059	0.203	1	299.1	51.4	0.936	0.016	120.1	16.5
15		1	Release Site	0.072	0.219	0.979	181.7	145.0	0.883	0.056	80.5	61.9
			Aquaria	0.043	0.211	0.998	233.9	92.3	0.916	0.031	94.7	34.9
		2	Release Site	0.053	0.289	0.938	125.2	115.7	0.852	0.080	55.6	48.3
			Aquaria	0.053	0.218	1	280.7	70.2	0.929	0.022	112.6	24.8

Release Mechanics												
%Pups	Duration	Interval	Population	r(s)	SD(r)	Pr(Persist)	N(Ext)	SD(N)	GD	SD(GD)	Adults	SD(Ads)
		3	Release Site	0.025	0.315	0.769	67.1	72.5	0.777	0.120	31.1	31.8
			Aquaria	0.058	0.209	1	295.6	57.1	0.934	0.018	118.6	19.1
	20	1	Release Site	0.082	0.209	0.998	250.0	167.9	0.905	0.045	109.1	70.6
			Aquaria	0.035	0.215	0.992	186.2	96.3	0.903	0.042	75.9	37.0
		2	Release Site	0.064	0.285	0.977	172.0	136.2	0.884	0.059	76.2	57.8
			Aquaria	0.048	0.221	1	258.3	82.5	0.926	0.022	104.0	30.3
		3	Release Site	0.047	0.315	0.948	120.0	103.3	0.854	0.083	53.6	44.0
			Aquaria	0.054	0.214	1	283.4	65.2	0.931	0.018	113.9	23.0
75	10	1	Release Site	0.051	0.244	0.906	94.0	87.4	0.815	0.103	43.2	38.0
			Aquaria	0.050	0.227	0.999	264.1	79.0	0.923	0.026	107.2	29.3
		2	Release Site	0.016	0.306	0.575	47.4	50.3	0.731	0.134	22.5	22.1
			Aquaria	0.057	0.228	1	290.3	59.5	0.933	0.017	116.9	20.2
		3	Release Site	0.010	0.318	0.558	42.7	46.0	0.727	0.126	20.6	21.1
			Aquaria	0.059	0.220	1	295.9	52.8	0.935	0.016	119.4	17.1
	15	1	Release Site	0.074	0.219	0.992	216.5	170.2	0.892	0.050	95.1	71.0
			Aquaria	0.035	0.236	0.994	186.7	94.5	0.900	0.042	76.6	37.2
		2	Release Site	0.056	0.290	0.961	148.4	134.8	0.864	0.074	66.3	56.9
			Aquaria	0.049	0.240	1	260.4	79.4	0.924	0.024	105.6	29.6
		3	Release Site	0.028	0.315	0.822	79.2	83.9	0.796	0.119	36.2	36.1
			Aquaria	0.057	0.226	0.999	289.4	61.6	0.933	0.018	116.7	21.1
	20	1	Release Site	0.082	0.213	0.999	288.8	197.6	0.912	0.037	126.0	83.4
			Aquaria	0.021	0.246	0.973	111.3	75.3	0.869	0.057	46.7	29.9
		2	Release Site	0.066	0.291	0.985	202.3	153.3	0.894	0.050	88.6	65.0
			Aquaria	0.042	0.249	0.999	227.3	92.9	0.916	0.031	92.7	35.2
		3	Release Site	0.049	0.317	0.969	138.9	113.3	0.867	0.070	61.9	48.4
			Aquaria	0.051	0.233	1	270.0	77.0	0.928	0.021	108.8	28.4

Table IV.3: Low Growth

Release Mechanics												
%Pups	Duration	Interval	Population	r(s)	SD(r)	Pr(Persist)	N(Ext)	SD(N)	GD	SD(GD)	Adults	SD(Ads)
25	10	1	Release Site	0.024	0.280	0.474	28.3	27.7	0.708	0.136	14.3	12.9
			Aquaria	0.058	0.186	1	296.7	57.7	0.935	0.016	118.6	19.6
		2	Release Site	-0.011	0.333	0.166	15.8	14.6	0.621	0.148	8.7	7.8
			Aquaria	0.061	0.186	1	304.0	48.5	0.937	0.017	121.3	15.1
		3	Release Site	-0.019	0.333	0.167	17.5	15.8	0.631	0.169	9.5	7.8
			Aquaria	0.062	0.183	1	303.7	48.7	0.938	0.014	121.1	14.8
15		1	Release Site	0.048	0.231	0.863	62.4	58.2	0.816	0.092	29.9	26.5
			Aquaria	0.053	0.186	0.999	282.9	68.0	0.931	0.019	113.4	24.2
		2	Release Site	0.023	0.304	0.695	39.2	37.9	0.760	0.130	19.1	17.2
			Aquaria	0.058	0.188	1	296.9	56.1	0.935	0.017	118.9	18.3
		3	Release Site	-0.005	0.330	0.384	23.7	23.8	0.687	0.150	12.1	11.1
			Aquaria	0.060	0.187	1	299.3	53.9	0.938	0.016	120.2	17.4
20		1	Release Site	0.064	0.211	0.98	98.0	76.0	0.869	0.063	45.4	33.3
			Aquaria	0.049	0.188	1	263.0	81.8	0.927	0.024	106.2	29.6
		2	Release Site	0.038	0.290	0.877	55.1	47.4	0.817	0.102	26.5	21.1
			Aquaria	0.056	0.192	1	294.5	58.0	0.935	0.016	118.0	19.5
		3	Release Site	0.018	0.326	0.737	39.9	36.8	0.777	0.115	19.6	16.7
			Aquaria	0.059	0.187	1	298.5	57.5	0.937	0.017	119.4	18.8
50	10	1	Release Site	0.029	0.267	0.729	38.5	38.4	0.749	0.133	18.9	17.8
			Aquaria	0.054	0.203	1	280.9	67.6	0.928	0.024	113.2	24.4
		2	Release Site	0.000	0.326	0.366	25.3	23.8	0.691	0.145	13.1	11.3
			Aquaria	0.058	0.210	1	299.7	54.6	0.935	0.017	119.9	17.3
		3	Release Site	-0.010	0.331	0.366	25.7	25.8	0.692	0.146	13.3	12.1
			Aquaria	0.060	0.204	1	301.0	49.2	0.936	0.016	120.9	15.0
15		1	Release Site	0.060	0.226	0.969	101.1	79.6	0.864	0.068	47.1	35.0
			Aquaria	0.044	0.208	0.997	239.7	88.8	0.918	0.031	97.5	34.0
		2	Release Site	0.038	0.303	0.894	69.7	62.5	0.828	0.093	33.1	28.0
			Aquaria	0.053	0.216	1	277.4	72.3	0.929	0.020	111.9	26.0

Release Mechanics												
%Pups	Duration	Interval	Population	r(s)	SD(r)	Pr(Persist)	N(Ext)	SD(N)	GD	SD(GD)	Adults	SD(Ads)
		3	Release Site	0.008	0.325	0.696	35.7	33.9	0.745	0.135	17.4	15.2
			Aquaria	0.058	0.209	1	295.1	55.8	0.935	0.016	118.4	18.8
	20	1	Release Site	0.069	0.216	0.994	145.4	101.5	0.895	0.056	66.5	43.9
			Aquaria	0.035	0.214	0.996	182.6	95.9	0.904	0.040	74.6	37.0
		2	Release Site	0.051	0.297	0.967	101.8	77.4	0.868	0.069	47.0	34.4
			Aquaria	0.048	0.222	1	257.5	79.9	0.925	0.025	104.2	29.8
		3	Release Site	0.032	0.328	0.916	70.3	62.6	0.837	0.090	33.6	28.4
			Aquaria	0.053	0.215	1	280.1	70.6	0.930	0.022	112.9	25.5
75	10	1	Release Site	0.034	0.258	0.797	52.0	48.4	0.784	0.119	25.3	22.2
			Aquaria	0.049	0.228	0.999	261.8	77.4	0.924	0.023	106.4	28.4
		2	Release Site	0.006	0.327	0.466	31.4	34.2	0.723	0.123	15.7	15.5
			Aquaria	0.058	0.226	1	295.2	54.8	0.934	0.017	118.6	18.7
		3	Release Site	0.002	0.325	0.447	27.6	28.0	0.704	0.132	13.9	12.9
			Aquaria	0.057	0.230	1	289.6	60.4	0.933	0.020	116.7	21.3
	15	1	Release Site	0.060	0.228	0.976	122.6	90.9	0.874	0.071	56.7	40.3
			Aquaria	0.035	0.237	0.998	186.2	95.7	0.899	0.043	76.0	37.3
		2	Release Site	0.039	0.304	0.933	79.1	72.2	0.840	0.088	37.6	32.5
			Aquaria	0.049	0.242	1	261.9	80.6	0.924	0.028	105.9	29.8
		3	Release Site	0.014	0.328	0.771	46.2	45.7	0.773	0.119	22.4	20.8
			Aquaria	0.055	0.226	1	286.6	62.4	0.933	0.019	115.8	21.7
	20	1	Release Site	0.069	0.218	0.991	164.3	107.0	0.902	0.044	75.3	47.6
			Aquaria	0.020	0.243	0.981	111.0	80.0	0.868	0.062	46.2	31.6
		2	Release Site	0.053	0.298	0.984	123.0	101.6	0.878	0.071	56.5	44.7
			Aquaria	0.043	0.248	0.999	234.5	90.1	0.919	0.027	94.9	34.2
		3	Release Site	0.037	0.334	0.945	86.6	70.5	0.854	0.075	40.2	31.4
			Aquaria	0.051	0.235	1	269.1	77.1	0.928	0.022	109.2	28.1

Table IV.4: Low Growth – El Niño

Release Mechanics												
%Pups	Duration	Interval	Population	r(s)	SD(r)	Pr(Persist)	N(Ext)	SD(N)	GD	SD(GD)	Adults	SD(Ads)
25	10	1	Release Site	0.008	0.311	0.243	16.4	15.3	0.669	0.154	8.7	7.5
			Aquaria	0.058	0.186	1	291.8	60.8	0.934	0.019	117.4	20.6
		2	Release Site	-0.025	0.358	0.08	11.5	8.9	0.628	0.126	6.3	4.5
			Aquaria	0.061	0.187	1	301.2	50.1	0.937	0.015	121.3	15.2
		3	Release Site	-0.041	0.362	0.06	13.0	14.4	0.635	0.167	6.4	5.7
			Aquaria	0.062	0.185	1	305.9	45.9	0.937	0.015	122.1	13.8
15	1	1	Release Site	0.029	0.260	0.701	29.7	26.0	0.777	0.111	14.7	12.2
			Aquaria	0.053	0.186	1	281.4	67.9	0.931	0.019	113.2	24.4
		2	Release Site	0.005	0.329	0.505	19.5	17.3	0.723	0.130	10.1	8.3
			Aquaria	0.058	0.188	1	296.2	57.6	0.935	0.018	118.7	19.0
		3	Release Site	-0.024	0.359	0.216	15.2	13.4	0.672	0.149	8.0	6.1
			Aquaria	0.061	0.184	1	300.4	50.8	0.937	0.016	120.7	16.6
20	1	1	Release Site	0.040	0.238	0.893	40.3	33.4	0.824	0.080	19.7	15.3
			Aquaria	0.048	0.188	1	260.2	82.0	0.925	0.026	104.9	30.5
		2	Release Site	0.017	0.319	0.73	28.0	24.1	0.779	0.105	13.8	10.9
			Aquaria	0.056	0.190	1	289.6	62.2	0.934	0.018	116.7	21.1
		3	Release Site	-0.004	0.356	0.55	20.7	20.4	0.735	0.133	10.3	8.8
			Aquaria	0.058	0.188	1	294.9	54.8	0.935	0.016	118.4	18.6
50	10	1	Release Site	0.012	0.294	0.473	21.0	20.8	0.713	0.138	10.7	9.5
			Aquaria	0.053	0.204	1	277.4	71.5	0.928	0.023	112.1	25.9
		2	Release Site	-0.016	0.358	0.205	13.5	11.5	0.649	0.142	7.1	5.1
			Aquaria	0.058	0.207	0.999	294.6	52.4	0.934	0.019	119.2	17.6
		3	Release Site	-0.029	0.358	0.206	15.1	14.3	0.666	0.145	8.1	6.6
			Aquaria	0.060	0.204	1	300.7	53.5	0.936	0.016	119.9	16.6
15	1	1	Release Site	0.035	0.250	0.877	43.2	40.8	0.812	0.099	21.0	18.5
			Aquaria	0.043	0.209	0.999	233.9	90.5	0.916	0.032	95.4	34.6
		2	Release Site	0.016	0.327	0.752	32.1	30.4	0.780	0.116	15.6	13.7
			Aquaria	0.052	0.217	1	274.7	70.0	0.929	0.021	111.7	25.4

Release Mechanics												
%Pups	Duration	Interval	Population	r(s)	SD(r)	Pr(Persist)	N(Ext)	SD(N)	GD	SD(GD)	Adults	SD(Ads)
		3	Release Site	-0.013	0.358	0.464	18.6	17.2	0.707	0.131	9.6	8.1
			Aquaria	0.057	0.208	1	293.5	56.9	0.935	0.017	117.9	19.1
	20	1	Release Site	0.048	0.235	0.958	64.2	53.7	0.860	0.073	30.5	24.3
			Aquaria	0.034	0.216	0.992	182.2	93.8	0.904	0.040	74.3	35.8
		2	Release Site	0.029	0.320	0.894	47.0	39.6	0.829	0.092	22.3	17.7
			Aquaria	0.048	0.222	1	262.5	77.6	0.927	0.022	106.3	28.9
		3	Release Site	0.011	0.355	0.802	33.7	31.0	0.799	0.098	16.4	13.9
			Aquaria	0.054	0.215	1	285.3	66.0	0.932	0.021	114.8	23.3
75	10	1	Release Site	0.015	0.287	0.583	25.3	24.8	0.741	0.120	12.8	11.4
			Aquaria	0.050	0.227	1	265.4	77.6	0.923	0.029	107.4	28.6
		2	Release Site	-0.014	0.357	0.278	17.5	17.6	0.681	0.143	8.9	8.0
			Aquaria	0.057	0.230	1	292.4	59.0	0.933	0.016	117.4	20.2
		3	Release Site	-0.024	0.361	0.264	15.3	14.7	0.677	0.141	8.0	6.7
			Aquaria	0.058	0.221	1	294.4	60.2	0.934	0.020	118.2	20.4
	15	1	Release Site	0.040	0.251	0.918	54.8	48.9	0.836	0.088	26.1	21.9
			Aquaria	0.035	0.236	0.995	189.4	94.6	0.901	0.042	77.5	36.6
		2	Release Site	0.021	0.327	0.81	39.8	35.3	0.809	0.097	19.3	15.9
			Aquaria	0.048	0.240	0.999	262.3	78.5	0.925	0.023	105.8	29.2
		3	Release Site	-0.008	0.356	0.546	22.2	21.0	0.739	0.109	11.1	9.9
			Aquaria	0.056	0.224	1	291.5	61.4	0.933	0.018	117.0	20.4
	20	1	Release Site	0.049	0.240	0.956	74.7	60.8	0.868	0.073	35.0	27.0
			Aquaria	0.020	0.248	0.974	111.0	76.3	0.867	0.065	46.5	30.5
		2	Release Site	0.031	0.320	0.92	54.9	50.2	0.841	0.084	25.9	22.0
			Aquaria	0.043	0.249	1	233.4	89.2	0.917	0.033	94.5	34.1
		3	Release Site	0.015	0.350	0.866	41.0	36.9	0.816	0.101	19.9	17.1
			Aquaria	0.051	0.233	1	272.0	73.9	0.927	0.022	109.4	26.9