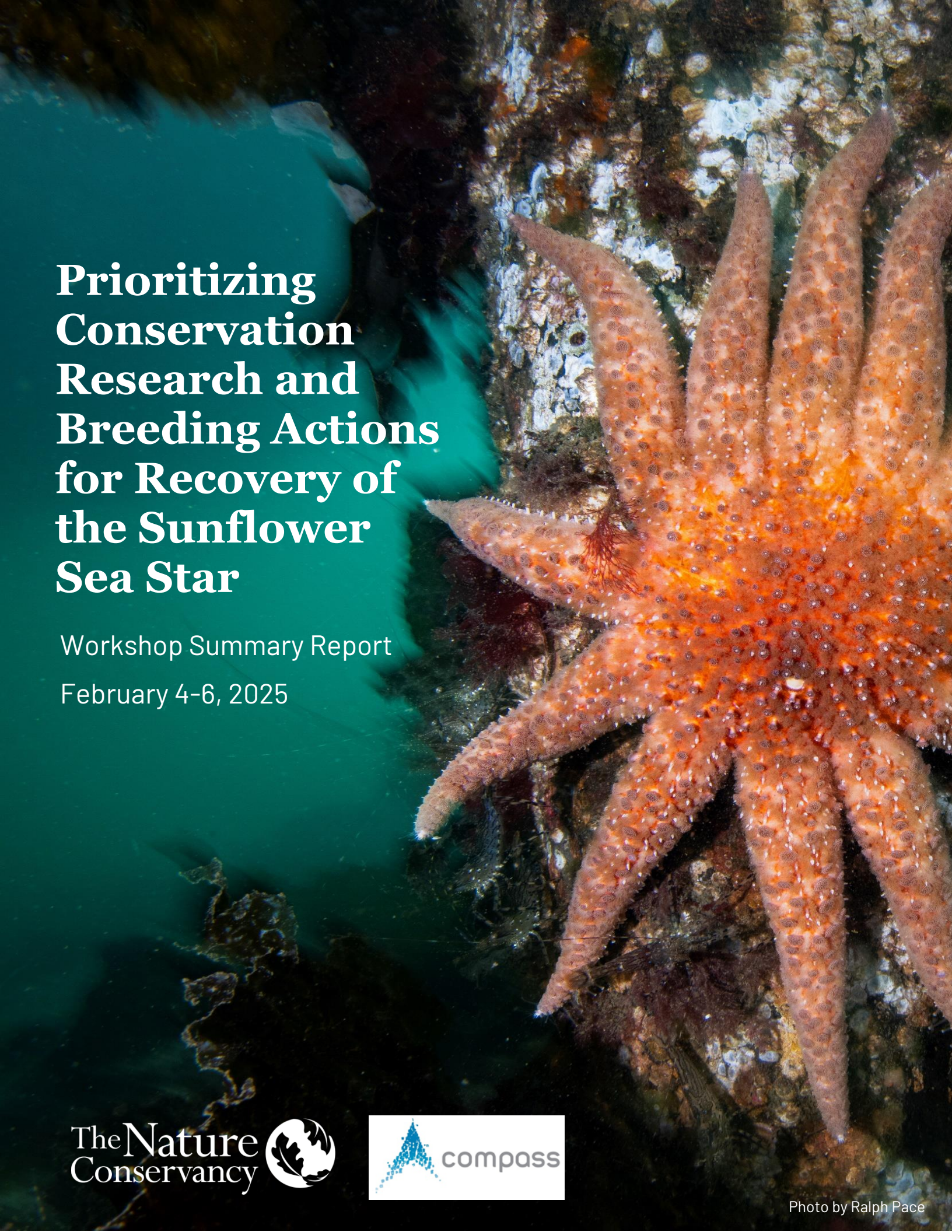
Prioritizing Conservation Research and Breeding Actions for Recovery of the Sunflower Sea Star

Workshop Summary Report

February 4-6, 2025



The Nature Conservancy

compass

Photo by Ralph Pace

Contents

1 Workshop & Process Overview 4
1.1 Background & Context 4
1.2 Connection with the Roadmap to Recovery 4
1.3 Decision Sketch Approach 5
2 Focal Issue & Objectives 6
3 Conservation Breeding Actions 8
4 Expected Consequences & Tradeoffs 10
5 Supported Actions & Research Needs 13
5.1 Support for Actions 13
5.2 Conservation Breeding Strategy 16
5.3 Research Needs & Uncertainties 16
Appendix A: Working Group Participants 19
Appendix B: Details on Research & Uncertainties 25

Suggested Citation:

The Nature Conservancy, Sacramento, CA. 2025. Prioritizing Conservation Research and Breeding Actions for Recovery of the Sunflower Sea Star. Workshop report. 28 pages.

Executive Summary

The Nature Conservancy (TNC) convened a workshop in February 2025 in Santa Barbara, CA to collaboratively investigate conservation breeding management and research options to promote resilience of the sunflower sea star to sea star wasting disease (SSWD). Workshop participants included representatives from State and Federal natural resource agencies, zoos and aquaria, the Kashia Band of Pomo Indians, non-governmental organizations, and academic researchers working on sunflower sea star recovery, captive breeding, SSWD, and similar efforts for other species. The purpose of this workshop was to take a deliberative, decision-focused approach for advancing a conservation breeding program. The group engaged in a series of research presentations and discussions that helped define key objectives that can be used to track "success" (Section 2), define a set of possible conservation breeding actions (Section 3), coarsely predict the consequences of actions across objectives and discuss expected tradeoffs (Section 4), and deliberate around preferred actions and remaining uncertainties that could be addressed with research and monitoring (Section 5).

Participants tended to support a strategy that integrates three promising conservation breeding actions for improving the resilience of sunflower sea stars to SSWD in an effort to recover the species in the wild:

1) **Expand cryobanking** activities across facilities, where reproductive samples would be collected from across the species' range, catalogued, and used to introduce genetic diversity into lab-based breeding efforts and preserve existing sea star genetic diversity for future research and management;
2) **Conduct multi-generation disease challenge trials (pedigree-based and genomic selection),** where lab studies could identify disease resistant family lines, heritable genetic traits, and external conditions that confer resilience;
3) **Explore biotic interventions (probiotics and phages)** in concert with challenge trials, where lab studies could identify microbe communities and phages associated with increased survival and disease resilience, and these biotic treatments could be given to sea stars prior to outplanting.

The group recognized that the degree these and other conservation breeding options can be implemented to the point of outplanting sea stars is contingent on addressing numerous uncertainties about species ecology, logistical constraints, and broader collaboration. Key uncertainties included (a) identification of heritable genetic traits, microbiomes, and other conditions that confer resilience, (b) how to reduce risk of disease transmission when bringing animals into captivity and monitoring of animals post-release, (c) how to coordinate complementary efforts across conservation breeding facilities and scale up capacity, if needed, and (d) how to extend collaborations across other interested parties (e.g., additional facilities, Tribes) to align goals and leverage knowledges for more effective and supported outcomes. See Section 5.3 for more details.

Overall, the workshop's outcomes serve as a high-level blueprint to guide forthcoming, coordinated research and implementation of approaches that may lead to the reintroduction of sunflower sea stars to nearshore waters.

1 Workshop & Process Overview

1.1 Background & Context

Sunflower Sea Star in Northern CA tide pools, photo by Brocken Inaglory

The Nature Conservancy (TNC) convened a Working Group to collaboratively investigate conservation breeding options to promote resilience of the sunflower sea star (*Pycnopodia helianthoides*) to sea star wasting disease (SSWD). Severe and rapid declines of sunflower sea stars, along with associated consequences to rocky reef ecosystems, have been documented since the major SSWD event in 2013. Because SSWD is believed to be the primary cause of the sunflower sea star decline, it is assumed (at least by some) that conservation breeding actions are a necessary tool to develop within the toolbox to increase resilience in captive and outplanted (i.e., captive-bred individuals released into their native habitats) sea stars and advance species recovery. See Appendix A for definitions of common terms used and discussed within this context.

The purpose of this effort was to take a deliberative, decision-focused approach for advancing a conservation breeding program – including defining key objectives that can be used to track "success," creating a set of possible conservation breeding actions, coarsely predicting their consequences, and deliberating on expected tradeoffs. **Ultimately, the process (and workshop) helped participants identify a set of promising conservation breeding actions and associated research needs for improving the resilience of sunflower sea stars to SSWD in an effort to recover the species in the wild. The group's discussions are expected to inform further planning of sea star research and recovery efforts.**

Along with TNC, the Working Group included participants from State and Federal natural resource agencies, a Tribal Nation with an active ecosystem and aquaculture research program (Kashia Band of Pomo Indians), non-governmental organizations, zoos and aquaria, captive breeding specialists, and academic researchers working on sunflower sea star recovery, captive breeding, SSWD, and similar efforts for other species. See Appendix B for a list of participants. Compass Resource Management facilitated the process.

1.2 Connection with the Roadmap to Recovery

The workshop was intended to address and support a subset of recommendations given in TNC's Roadmap to Recovery (Heady et al. 2022; Fig 1). Specifically, the Roadmap called to "continue, refine, and expand research on disease and disease mitigation" (Objective 3) and to "continue and expand captive rearing efforts for scientific research and potential population recovery" (Objective 4). A recommended next step was the development of a captive breeding program to research causes

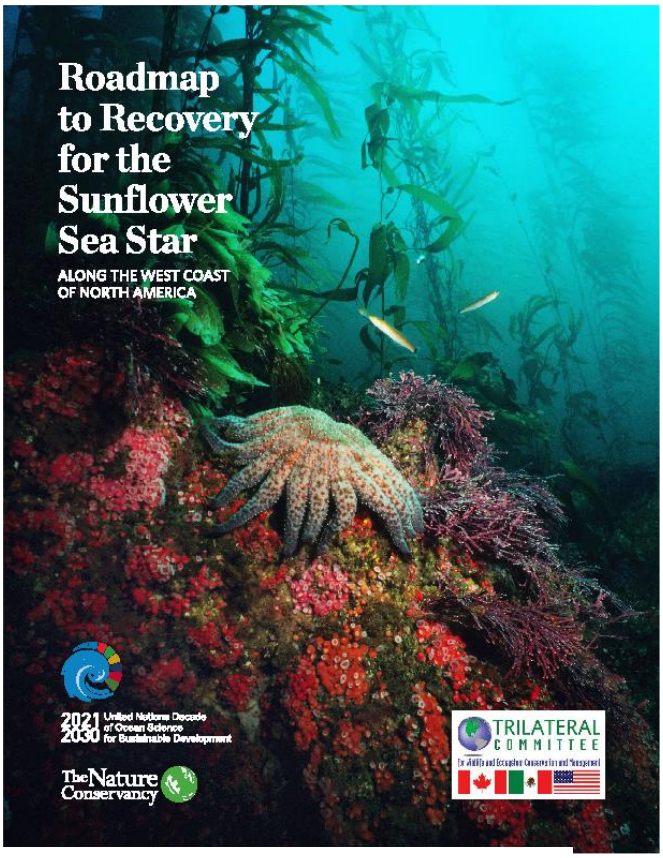


Figure 1. Roadmap to Recovery for the Sunflower Sea Star

and conditions of disease/resilience, culture large numbers of individuals to maintain genetic diversity, to act as reservoirs of genetic stock, to serve as insurance against further losses in the wild, and to support the long-term goal of outplanting on reefs under appropriate conditions. Focusing the workshop on promising captive breeding actions and research priorities advanced Objectives 3 and 4. It also served as a necessary first step toward Objective 5 – determine how best to translocate or outplant sea stars to recover populations. At the workshop, captive breeding actions were discussed in context of the broader goal of outplanting resilient individuals. The Roadmap also calls for developing recovery goals and criteria (Objective 1). By taking a decision-focused approach in the workshop, the group identified shared objectives and performance measures to evaluate success over time through captive breeding and related efforts.

1.3 Decision Sketch Approach

The approach for the workshop was centered on structured decision making (SDM), a method for helping groups work collaboratively on complex decisions. Through an SDM process, participants build a shared understanding of the focal decision, clarify expected outcomes and uncertainties, explore tradeoffs, and make informed and transparent choices (Figure 2). Specifically, the process involves identifying a focal *Problem/Decision* and the related context, defining the *Objectives* that are important to consider for that decision (e.g., disease resilience/survival in the wild, cost), creating *Alternatives/Actions* to address these objectives (e.g., challenge trials, probiotic treatments, etc.), predicting the *Consequences* of the alternatives on objectives (e.g., what is the likelihood of disease resilience in sea stars if we apply treatment A vs B),

Figure 2. Steps in SDM process. The process is iterative (grey arrows) and linked to learning and feedback (dotted orange arrows).

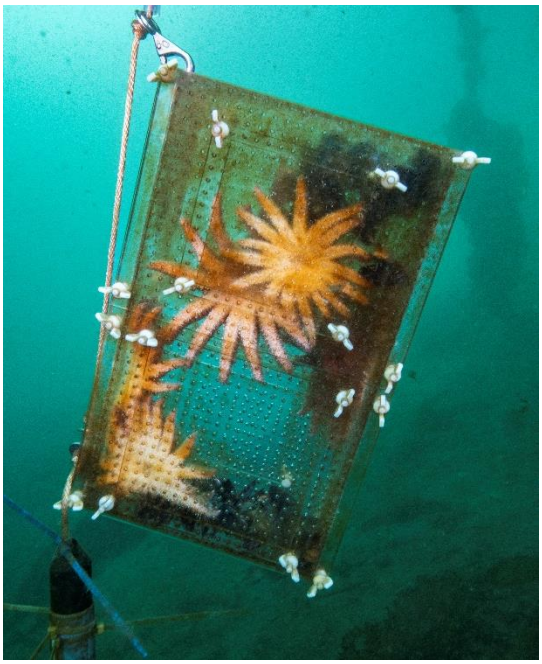
and exploring *Tradeoffs* to help identify preferred alternatives. The process typically involves iteration and may be linked to monitoring and learning.

For this workshop, we used "decision sketching": an approach to SDM where groups quickly go through the SDM steps for a simplified version of the problem, discuss key insights and uncertainties, and test whether there is sufficient information to identify a preferred action(s) or reveal where more information and deliberation is necessary to make an informed decision. The SDM process provided an opportunity for participants to share their knowledge in an integrated manner, supporting focused discussion on information that is critical to moving forward with supported options.

The remaining sections in this document summarize outcomes of workshop discussions around the scope of the focal issue and objectives, actions, consequences and tradeoffs, preferred actions, and remaining uncertainties and research needs.

2 Focal Issue & Objectives

The focal issue discussed in this process was stated as: Identify the best conservation breeding actions and priority research needs to promote sunflower sea star resilience to SSWD in captive and outplanted individuals, while considering genetic diversity and other interests. Breeding actions and research should be implemented in a way that will reduce uncertainty in the future. The group acknowledged related decisions/issues outside the scope of the current process which could be informed and addressed later. These related issues included (a) identifying the best places to put outplanted sea stars, (b) identifying the best actions for sea star recovery that are not associated with conservation breeding, and (c) identifying the best options for expanding conservation breeding facilities or other more specific husbandry methods that could be refined regardless of priority actions.



Experimental outplanting of sunflower sea stars in Friday Harbor, WA, photo by Ralph Pace

Objectives represent the fundamental interests that the group is seeking to achieve that can be affected, in this case, by conservation breeding actions. Each objective has corresponding "Performance Measures" (PMs) that help track their achievement, given different actions.

The group discussed and identified a set of objectives and PMs in the decision sketch (Table 1). The list is not exhaustive of all interests that could be affected by conservation breeding actions, but it likely captures priority interests useful for identifying priority actions and uncertainties to resolve. The objectives listed below provide a framework for evaluating actions and comparing their relative advantages and disadvantages. The PMs in this decision sketch were designed to be simplistic, given the limited time and information (e.g., expert judgment) the group used to assess them. For

example, many PMs relied on 4- or 5-point constructed scales to assess relative impacts on the objectives. Objectives and PMs could be added or modified through a fulsome SDM process as additional information is collected (e.g., through empirical research/modeling). Still, this simplified set is a useful starting point for establishing common conservation objectives across multiple partners working toward sunflower sea star recovery.

Table 1. Objectives and corresponding performance measures for guiding conservation breeding decisions for sunflower sea star resilience to SSWD.

Objective	Description and Performance Measure	Preferred Direction
Captive breeding population		
Disease resilience	Represents an interest in increasing sea star resilience and survival from SSWD. Measured as: out of 100 sunflower sea stars, the % that are resilient and survive SSWD in captivity (0-100%).	Higher
Genetic diversity	Represents an interest to preserve natural genetic variability and potential resilience to existing and emerging conditions. Measured with a constructed scale: 1 = Very Low; 2 = Low; 3 = Moderate; 4 = High; 5 = Very High / historical natural diversity	Higher
Local target population (including outplanted, translocated, or other individuals)		
Disease resilience	Represents an interest in increasing sea star resilience and survival from SSWD, as well as the overall fitness of outplanted individuals. Measured as: out of 100 sunflower sea stars, the % that are resilient and survive SSWD in the wild (0-100%).	Higher
Certainty of resilience	Represents an interest in assessing the degree of certainty for expected benefits of actions on resilience and considering this alongside the magnitude of resilience benefits and other outcomes. Measured with a constructed scale: 1 = Very Low. Uncertain theoretical foundation with little or inconsistent empirical support. 2 = Low: Firm theoretical foundation, one or more empirical studies that show mixed inconsistent effects in resilience for focal or other species. 3 = Firm theoretical foundation, one or more empirical studies that support increases in resilience of other species, with some work on focal species. 4 = Firm theoretical foundation, one or more empirical studies that support increases in resilience of focal species.	Higher
Genetic diversity	Represents an interest to preserve natural genetic variability and potential resilience to existing and emerging conditions. Measured with a constructed scale: 1 = Very Low; 2 = Low; 3 = Moderate; 4 = High; 5 = Very High / historical natural diversity	Higher
Ecosystem		
Ecological impacts	Represents an interest in restoring broader coastal ecosystems (including humans). Impact to ecosystem, given	Higher

Objective	Description and Performance Measure	Preferred Direction
	actions (e.g., releasing individuals from captivity, probiotics). Measured as constructed scale: -2 = Strong negative impacts; -1 = slight negative impacts; 0 = neutral impacts; 1 = slight positive impacts; 2 = strong positive impacts	
Implementation & Learning		
Time to implementation	Represents an interest in finding and implementing effective actions soon to reverse declines of sea stars. Accounts for relative ease of implementation (technical feasibility, regulatory/permitting feasibility). Specifically, time to first outplanting. Measured with a constructed scale: <1 yr; 1-3 yrs; 4-6 yrs; 7-10 yrs; >10 yrs	Lower
Cost	Represents an interest in using conservation resources efficiently. Measured with a constructed scale: 1 = Very Low; 2 = Low; 3 = Moderate; 4 = High; 5 = Very High	Lower
Learning	Represents an interest in increasing scientific advancements to apply in the future to sunflower sea stars and other species. Measured with a constructed scale: 1 = Very Low; 2 = Low; 3 = Moderate; 4 = High; 5 = Very High	Higher
Ethical considerations		
Animal stress	Represents an interest in minimizing any stress, mortality, or any other changes to the natural conditions of sea stars caused by methods used in the action. Measured with a constructed scale around the degree of disturbance to animals relative to natural conditions: 1 = Very Low; 2 = Low; 3 = Moderate; 4 = High; 5 = Very High	Lower

3 Conservation Breeding Actions

Sunflower Sea Stars at Friday Harbor Labs, WA, photo by Norah Eddy

Actions in the decision sketch are ways of breeding and treating sea stars to support disease resilience. The group brainstormed and defined multiple actions that could be implemented at conservation breeding facilities. The group first considered these as individual, distinct options in the decision sketch process but later discussed ways to combine them into a management and research strategy (see Section 5). The group defined four distinct actions that could be taken using conservation breeding facilities – non-selective methods to maximize genetic diversity, two challenge trial actions, and biotic treatments. They also defined two "reference" options (do nothing and

translocations) representing status quo actions to serve as helpful comparisons with options associated with captive breeding methods. See Table 2 for the list of actions considered in the decision sketch.

The group also discussed and defined a reasonable scale for actions to consider in the decision sketch. Due to the degree of uncertainty associated with the system and potential actions, the group defined a "proof of concept" scale for implementing actions (i.e., outplanting or translocating sea stars) at 2-5 sites within the range of Northern California, Oregon, and/or Washington.

The group briefly discussed the action to do gene editing. Ultimately, they decided to table this option for now and not evaluate and consider it further in the decision sketch process. Participants noted that gene editing would take the longest to refine and implement and involve navigating unique ethical concerns; therefore, it would only be considered in the future, if needed, once other options were explored.

Table 2. Possible conservation breeding and reference actions for advancing sunflower sea star recovery and resilience to SSWD.

Action	Definition	Details
Do nothing (no captive breeding or translocations)	No captive breeding actions, no release of individuals into wild: reference option.	Other recovery actions continue.
Translocations (reference option)	Transport and rerelease of sea stars from one location to another. Translocation is defined when the animals are not produced in captive facilities/labs.	Local first. Could translocate different life stages. Assume we screen individuals for disease before release. Monitor locations. Engaging local communities and knowledges is needed.
Captive breeding to maximize genetic diversity	Breed sea stars in captivity and outplant individuals using methods to maximize genetic diversity (without selective breeding for resilience).	Incorporate cryobanking of genetic material. Do pairwise breeding, then recombine offspring. Confirm genetic diversity, relative to control crosses. Release using modernized conservation genetics criteria.
Challenge trials (w/ pedigree-based genetic selection)	Conduct challenge/exposure trials to identify disease-resilient individuals/families. Then breed/release any resilient families.	Experimental exposures: varying pathogen dose, post exposure treatment, temp, etc. Immune priming experiments with larvae and juveniles. Phased research.
Challenge trials (w/ genomic selection)	Conduct challenge/exposure trials to identify disease-resilient individuals. Use genomic analysis to select and propagate most resilient animals within families for eventual release.	Same details as pedigree-based trials. Genomic selection methods may identify resilient individuals faster than pedigree-based methods due to individual- and not family-based selection.

Action	Definition	Details
Biotic treatments	Identify microbial communities or bacteriophage(s)to improve outcomes (e.g., growth, survival, and disease resilience). Then inoculate other individuals with microbes and release into wild.	Phage therapy – identify beneficial phage that improves disease resilience.
Gene editing	After identifying a link between resilience to SSWD and genotype, edit individual sea star's genotypes and release individuals into wild.	Do not evaluate in decision sketch. Not enough information for now; concerns about releasing gene-edited animals in wild. Revisit as longer-term tool to support recovery efforts.

4 Expected Consequences & Tradeoffs

After defining a set of objectives and conservation breeding actions, the Working Group used expert judgment to predict coarse consequences of the actions on the objectives. First, participants worked through a guided expert elicitation exercise to provide individual best judgments for the consequences of each action on the objectives. Participants could omit responses to any part of the exercise if they felt they did not have sufficient knowledge about the topic. Second, responses were summarized across the group, including the median and range of consequences. Finally, the group discussed rationale behind responses and agreed on final, representative values to use moving forward that capture approximate outcomes of actions across objectives.

Final values for expected outcomes of conservation breeding and reference actions were summarized and presented to the group in a consequence (Table 3). Consequence tables are a common tool in SDM processes for organizing predicted outcomes (cells), where rows indicate the set of objectives (and PMs), and columns indicate the set of distinct actions. Some objectives did not apply to all actions, and outcomes were not predicted in these cases (see blank cells in the consequence table). For example, the do nothing and translocation options did not involve taking animals into captivity, so captive breeding population outcomes were not affected or considered.

The group discussed some emerging tradeoffs and takeaways from the consequence table:

- Expected patterns were seen comparing the four conservation breeding actions (the right four actions in the consequence table) with the two reference actions. Conservation breeding actions generally performed better than reference actions for disease resilience, genetic diversity, ecosystem impacts, and learning. Reference actions performed better for time to implementation, cost, and degree of animal stress.
- **Disease resilience** in captive and outplanted sea stars was most likely to be conferred for the challenge trials and biotic actions, with captive breeding to maximize genetic diversity having a lower likelihood of conferring resilience since it did not employ selective methods.
- **Genetic diversity** in captive and outplanted sea stars was highest for the captive breeding to maximize genetic diversity approach, although other conservation breeding actions also had relatively high expected genetic diversity as long as appropriate methods were used.

- The conservation breeding actions also were expected to result in **benefits for the ecosystem** because they were more likely to support resilient populations of sea stars that fulfill ecological roles of controlling sea urchins and promoting kelp forests. Conservation breeding actions, relative to reference actions, also had higher expected **benefits for learning**, as they offered more opportunities for controlled studies of sea star genetics and ecology in captive facilities.
- The conservation breeding actions ranged in **time to full implementation** (when methods could be honed and resilient sea stars could be outplanted at limited sites) from 1-3 years to 7-10 years, with pedigree-based challenge trials having the longest time to implementation.
- The conservation breeding actions were expected to have higher **costs** and **animal stress**, relative to reference actions, due to the nature of bringing in, caring for, and conducting research on animals in captivity. Pedigree-based challenge trials had the highest expected costs due to the longer time to implementation that would include more staff time and facility resources.
- All actions included some **degree of uncertainty** around their ability to promote resilience to SSWD that will need to be addressed with further research.

Table 3. Consequence table of predicted outcomes of conservation breeding and reference actions across objectives/performance measures. See Table 1 for descriptions of objectives and performance measures. Green cells indicate performance measures where higher values (darker shades) are preferred. Orange cells indicate metrics where lower values (lighter shades) are preferred.

Objective (Less Preferred … More Preferred)	Performance Measure	Unit	Preferred Direction	Do nothing (ref)	Translocation (ref)	Breeding to max genetic diversity	Challenge trials (pedigree-based)	Challenge trials (genomic)	Biotic treatments
Captive breeding population									
Disease resilience	Probability of disease resilience	%	Higher			5	50	68	50
Genetic diversity	Constructed scale (1 to 5)	1 to 5	Higher			4	3	3.5	3
Outplanted/translocated population									
Disease resilience	Probability of disease resilience	%	Higher	5	5	5	45	60	30
Certainty of resilience	Constructed scale (1 to 4)	1 to 4	Higher	3	1.5	2	3	3	2
Genetic diversity	Constructed scale (1 to 5)	1 to 5	Higher	2	2.5	4	3	3.5	3
Ecosystem									
Ecosystem impacts	Constructed scale (-2 to 2)	-2 to 2	Higher	-1	-0.5	1	1.5	2	1
Implementation									
Time to implementation	Constructed scale (1 to 5)	1 to 5	Lower	<1 yr	1-3 yrs	1-3 yrs	7-10 yrs	4-6 yrs	1-3 yrs
Cost	Constructed scale (1 to 5)	1 to 5	Lower	1	2	3	5	4.5	3
Learning	Constructed scale (1 to 5)	1 to 5	Higher	1	2	3	4	5	4.5
Ethical considerations									
Degree of animal stress	Constructed scale (1 to 5)	1 to 5	Lower		2	3	4	4	4

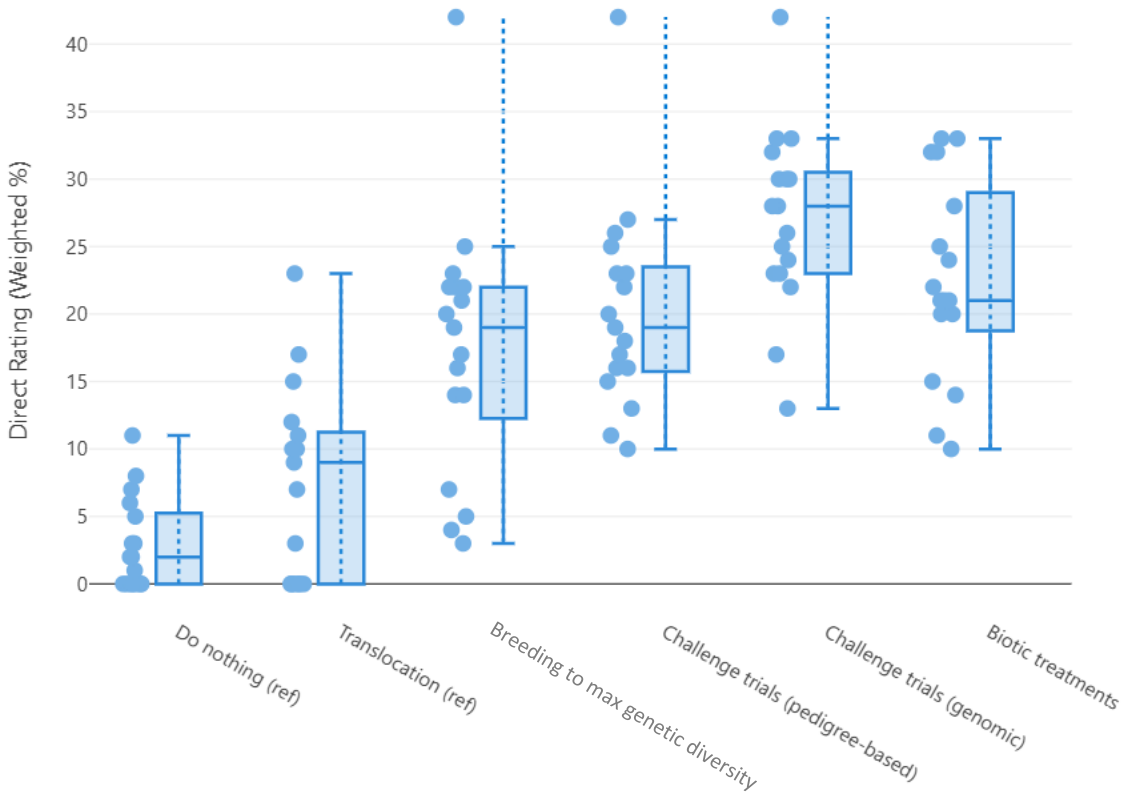
5 Supported Actions & Research Needs

5.1 Support for Actions

In the last session of the workshop, participants discussed tradeoffs, preferred actions, and next steps. After reviewing the tradeoffs across all actions and performance measures, the group expressed preferences for actions through an exercise where they directly rated each action by level of support.

Results showing the degree of support for each action are shown in Figure 3. Overall, the do nothing action was least supported; translocation also had low support, but higher and more mixed levels of support relative to do nothing. The four conservation breeding actions (captive breeding to maximize genetic diversity, both challenge trial actions, and biotic treatments) had higher support than the two reference actions, and group members tended to spread their level of support across multiple conservation breeding actions. On average, challenge trials with genomic selection was the most supported action.

Figure 3. Workshop participants' (n = 17) relative degree of support for candidate conservation breeding and reference actions. Dots represent individual's responses and box-and-whiskers represent medians and ranges of responses across the group. Responses were originally on the scale of 0 (least preferred) to 100 (most preferred) and were then rescaled to a relative weight, such that each participant's set of scores summed to 100.



The group's rationale for level of support and remaining concerns for each action are summarized in Table 4.

Table 4. Summary of Working Group rationale for supporting actions or remaining concerns that capture expected tradeoffs.

Action	Rationale for support	Concerns
Do nothing (no captive breeding or translocations)	• Natural recovery is possible; boom-and-bust cycles have been observed in similar species/systems.	• Natural recovery is not likely, and irreversible effects to kelp ecosystems could occur without intervention.
Translocations (reference option)	• Translocation could be done alongside other actions. • There are spatial disparities in status of the species (i.e., plenty of animals in the north), and genetic research shows a high degree of similarity across range. • May be implemented quickly and at a lower cost, relative to other actions. • May explore translocating adults and larvae. • May be helpful to find and translocate isolated individuals into higher density populations.	• It is likely not sufficient on its own to achieve sea star recovery. • The possibility of transporting disease is high, and action still involves some degree of animal stress. • May be hard to get approval to put AK animals into CA waters.
Captive breeding to maximize genetic diversity	• May be done alongside all of the other actions, at least in the form of capturing existing genetic diversity through cryobanking. • May be implemented more quickly than other options (e.g., challenge trials). • Maximizes the long-term success for other actions and research. For example, white abalone started way too late and now they have low genetic diversity. Maximizing genetic diversity in captive individuals can promote success for finding resilience through challenge trials. • Preserving genetic diversity can improve likelihood of finding resilient individuals for future diseases.	• It is likely not sufficient on its own to achieve sea star recovery.
Challenge trials (pedigree-based genetic selection)	• Relatively higher likelihood of advancing disease resilience. • Opportunity to learn about disease in sea stars. • May be easier to implement and understand (relative to challenge trials with genomic selection) that could	• This action's success is contingent on resilience being genetically heritable, which there is currently no evidence. • May take longer (higher time to implementation and cost) and be less precise

Action	Rationale for support	Concerns
	create opportunities for broader, public groups to be involved.	in finding resilient individuals compared to genomic selection methods.
Challenge trials (w/ genomic selection)	• Highest expected likelihood of advancing disease resilience, relative to other candidate actions. • Potential for finding resilient individuals faster (fewer generations) than pedigree-based methods, which would require shorter time to implementation and lower overall cost. • Best opportunity to learn about disease in sea stars.	• This action's success is contingent on resilience being genetically heritable, which there is currently no evidence. • May be more difficult to implement (relative to challenge trials with pedigree-based selection) that could limit which facilities could perform action, as well as limit opportunities for broader, public engagement.
Biotic treatments	• Opportunity to learn about disease in sea stars. • May be faster to implement, relative to other actions (e.g., challenge trials). • May be done alongside other actions. • Good evidence that probiotics work from Oregon Aquarium; phages were naturally introduced in the pathogen impacting black abalone, reducing virulence of the pathogen. • If selective approaches do not work and/or there is no natural resistance to disease, biotics may be best chance of success. • Likely scalable across facilities.	• May be less effective at promoting disease resilience in outplanted/wild populations, relative to challenge trials; unknown degree of horizontal and vertical transmission among individuals. • Unknown scalability in the wild, and may be challenging to get permits/approval. • Unknown effects of releasing probiotics/phages used in captivity into wild ecosystems.

5.2 Conservation Breeding Strategy

The group built on these tradeoffs and preferences to discuss how actions could be combined and pursued in parallel within a strategy for advancing conservation breeding. The group noted that the actions evaluated thus far were not mutually exclusive, and pursuing multiple actions simultaneously was strongly supported.

Ultimately, participants tended to support a strategy composed of a set of three promising conservation breeding actions that could be pursued in parallel and integrated together for improving the resilience of sunflower sea stars to SSWD in an effort to recover the species in the wild:

1) **Expand cryobanking** activities across facilities, where reproductive samples would be collected from across the species' range, cataloged, and used to integrate into captive breeding programs as well as preserve existing sea star genetic diversity for future research and management;
2) **Conduct multi-generation disease challenge trials (pedigree-based and genomic selection),** where lab studies could identify disease resilient family lines, heritable genetic traits, and external conditions that confer resilience;
3) **Apply biotic methods (probiotics and phages)** in concert with challenge trials, where lab studies could identify microbe communities and phages associated with increased survival and disease resilience, and these biotic treatments could be given to sea stars prior to outplanting.

Overall, the workshop's outcomes (including the above strategy and research needs described below) serve as a high-level blueprint to guide forthcoming, coordinated research and implementation of approaches that may lead to the reintroduction of sunflower sea stars to nearshore waters.

5.3 Research Needs & Uncertainties

Finally, the group identified key uncertainties, and began brainstorming next steps for research, planning, and engagement to advance conservation breeding actions. The group recognized that the degree these and other conservation breeding options can be implemented to the point of outplanting sea stars is contingent on addressing numerous uncertainties about species ecology, logistical constraints, and broader collaboration. Research needs and uncertainties are summarized by different actions/categories below, and raw notes capturing the group's ideas are provided in Appendix C.

Research and monitoring to support other actions

- Develop effective and scalable methods to screen animals collected in the wild for disease to reduce transmission risk when collecting them for captive breeding efforts. Research time needed for isolation (and interactions, e.g., temperature-dependent) to address uncertainty around risk of disease transmission from wild individuals to captivity.
- Develop effective and scalable methods to screen for causative agent in sunflower sea stars, other species, and the environment. Samples could be compared pre- and post-disease outbreak. This could address key uncertainties related to the origin of causative agent,

geographic variation, multi-species dynamics, and conditions associated with disease outbreaks.

- Continue monitoring wild population trends and genetics to address uncertainty of disease resilience and recovery occurring naturally.
- Identify and collect sea stars from additional source populations that could be prioritized for conservation breeding actions.
- Contingent on the advancement of captive breeding actions to the point disease-resilient sea stars could be outplanted, a future research need will be to develop coordinated monitoring programs for post-release survival. A key ecological uncertainty will be the post-release survival of captive-bred and released sea stars. Monitoring to understand trends in survival is essential for adjusting conservation actions.

Ensuring adequate genetic diversity in broodstock and cryobanking of genetic material

- Initiate broad effort of collecting broodstock and cryobanking of sea star gametes and larvae. Initially collect samples from across species' range. Increase genetic diversity across broodstock and cryobanked specimens, and continue to assess which genetic traits are being integrated into captive brreding programs and cryobanked and how they relate to emerging information on disease resilience (e.g., from challenge trials).
- Continue to maintain and build out a shared database of sea stars and genetics in captive facilities (i.e., Zoological Information Management System [ZIMS] framework).
- Coordinate across facilities to align goals, allocate resources, and leverage knowledge (e.g., from AZA network).
- Establish at least one facility to captively raise animals with the sole purpose of maximizing genetic diversity. This could minimize the risk of disease transmission, relative to other facilities where wild sea stars (and potentially the disease) are brought in.

Challenge trials for disease resilience

- Continue and further develop challenge trial research in captive facilities. Research efforts should include the following steps: (a) identify if there is any resilience in sunflower sea stars to SSWD by testing different dosages, life stages, and other environmental conditions (e.g., O2, temperature); and (b) identify if that resilience is genetically linked and heritable through a quantitative genetic challenge study and other methods. These efforts could address the key ecological uncertainties: Is there any survival after exposure, and under what conditions? If we find resistance or tolerance, are they genetically linked?
- Coordinate across facilities to align goals, assess infrastructure and capacity to do challenge trials (including biosecurity capabilities), allocate resources, and leverage knowledge (e.g., from AZA network). A key uncertainty is how to sufficiently scale up sample sizes for challenge trial research, given current facility capacity or if facilities need to be built out.
- Leverage cryobanking samples and database to conduct challenge trials with broodstock and preserved samples that systematically explore genetic diversity and identify any genetic traits related to disease resilience.
- Continue to develop best captive breeding practices (e.g., number of generations in captivity, group size, isolation time, etc.) to minimize risk of unintended genetic and behavioral effects, as well as increase health and survival in captivity and upon release.

Biotic treatments

- Identify any probiotic communities and phages associated with increased health, survival, and disease resilience to the causative agent. A key ecological uncertainty is if probiotics and phages exist for this agent.
- Monitor how sea stars treated with biotics in captivity survive and explore potential methods to apply biotic treatments to wild populations.
- Develop best practices for incorporating probiotic and phage treatments into challenge trials and other conservation breeding actions.
- Examine multi-host dynamics for probiotic and phage treatments.

Additional engagement and communication

- Consider engaging researchers already studying causative agent or working in other similar contexts where species were headstarted for recovery after near-total die-offs from disease.
- Consider engaging Tribes and other local coastal communities to leverage knowledge and perspectives on sea star recovery, coordinate involvement in monitoring, and navigate acceptable ways to collect and outplant sea stars.
- Consider engaging public groups in pedigree-based challenge trials to improve education and support of sea star recovery.
- Consider continuing to engage legislators/permitters to facilitate support and approval of steps involved in conservation breeding actions (e.g., collecting and releasing sea stars from CA and other waters).

Appendix A: Working Group Participants

Working Group members and organizations.

Organization	Working Group Member
University of Washington	Dr. Jason Hodin
University of Washington	Dr. Drew Harvel
University of Washington	Dr. Alyssa Gehman
University of Washington	Dr. Robin Waples
UC Merced	Dr. Mike Dawson
Sunflower Star Laboratory	Dr. Lauren Schiebelhut
San Diego Zoo and Wildlife A	Dr. Oliver Ryder
UC Santa Barbara	Dr. Becky Vega Thurber
UC Santa Barbara	Dr. Jenn Caselle
UNC Wilmington	Dr. Blake Ushijima
Cal Academy of Sciences	Dr. Elora Lopez-Nandam
USDA Agricultural Research Service	Dr. Neil Thompson
California Department of Fish and Wildlife	Andrew Weltz
National Oceanic and Atmospheric Admin.	Dr. Alison Moulding
National Oceanic and Atmospheric Admin.	Dr. Barry Berejikian
Kashia Band of Pomo Indians	Dr. Dan Swezey
Kashia Band of Pomo Indians	Nina Hapner
The Nature Conservancy	Dr. Jono Wilson
The Nature Conservancy	Norah Eddy

Dr. Barry Berejikian is the Program Manager for Fisheries Enhancement and Conservation (FEC) at the Northwest Fisheries Science Center and Station Chief for the Manchester Research Station, which supports research on restoration and commercial aquaculture of finfish and shellfish and ecological interactions in Puget Sound. Barry received a B.S. degree in Environmental and Systematic Biology from California Polytechnic State University, San Luis Obispo in 1990, Master's (1992) and Ph.D. (1995) degrees in Fisheries from the University of Washington, and joined the Northwest Fisheries Science Center in 1995. The FEC Program focuses on the guiding the appropriate uses of artificial propagation for recovery of anadromous salmonids by generating empirical research on genetic and ecological interactions. Research scales range from laboratory investigations of fish behavior to ecosystem-scale studies of natural populations. Past research has compared the reproductive behavior and breeding success of hatchery and wild salmon, assessed competitive interactions among juveniles, assessed the performance of salmon reared full term in captivity (i.e., captive broodstocks), evaluated the effectiveness of alarm substances in generating conditioned anti-predator responses, and evaluated stock enhancement rearing approaches for marine species (rockfish and lingcod).

Dr. Jenn Caselle is a marine ecologist and Research Biologist at the Marine Science Institute, University of California Santa Barbara. Jenn has expertise in fisheries and marine conservation and has worked extensively in both tropical and temperate marine ecosystems. She has a long history in managing large field-based projects around the world and a strong record of fundraising. Jenn has worked extensively on design and monitoring of Marine Protected Areas and is also a PI for PISCO (Partnership for Interdisciplinary Studies of Coastal Oceans; www.piscoweb.org). The Caselle lab at

UCSB is fully committed to contributing to science through research and education and believes that mission cannot happen without an environment that is open, equitable, and inclusive to all. Her lab makes conscious efforts to provide a space for all people to be encouraged and heard. She received her B.S. in Zoology from U.C Berkeley and her PhD in Ecology from U.C Santa Barbara.

Dr. Mike Dawson (University of California, Merced) is an evolutionary ecologist interested in interactions between organisms and their environments that shape patterns of marine biodiversity across spatial and temporal scales. We analyze long-term time-series, original field survey, and multi-omics datasets using comparative approaches and population genomic and phylogenetic methods. Mike has been studying sea star responses to environmental perturbations in the northeastern Pacific since 2012.

Norah Eddy leads TNC's Ocean Recovery initiative and has dedicated her life to protecting wild places, natural resources, and the communities that depend on them. She has spent her career applying an entrepreneurial and innovative lens in a relentless pursuit of impact in ocean conservation. In 2014, she founded a mission-based seafood company with the aim of creating positive change in the seafood industry. At TNC, she leads an interdisciplinary team to deliver cutting edge science, tools, and policies to recover kelp, native oyster, and seagrass ecosystems across California and around the world. With over a decade in the marine conservation space, she has experience working closely with a diverse suite of ocean stakeholders to develop creative solutions and work towards shared objectives. Norah's work has been featured in The New York Times, Forbes, NPR, National Geographic, The Today Show, and The Huffington Post and she was a TEDx presenter in 2017. She holds a BS in Marine Biology from the College of Charleston and a Master of Environmental Science & Management from UCSB's Bren School.

Dr. Alyssa-Lois Gehman is a PI at the Hakai Institute and Adjunct Professor at the University of British Columbia, whose current research focuses on marine disease ecology. Alyssa's research explores how host-parasite interactions shape or are shaped by ecological communities and their environment. Some current projects in Alyssa's group focus on sea star wasting disease, rhizophalan infection in hermit crabs and integrating symbionts into biodiversity research. She received her PhD from the Odum School of Ecology at the University of Georgia in 2016 and her M.S. degree from Western Washington University in 2008.

Nina Hapner is the Managing Director of Environmental Planning and Natural Resources for the Kashia Band of Pomo Indians. She holds a BS, Wildlife Biology from Cal Poly Humboldt. She has worked in the field of natural resources over 25 years. She oversees, with brilliant staff: Water Quality (including drought management), Solid Waste, Air Quality, Education & Outreach, Environmental Ordinance Development and Roads Development, Marine Monitoring Activities, Bear Monitoring, Forest & Grassland Management, Endangered Species Surveys, etc.

Dr. Drew Harvell is Professor Emerita of Ecology and Evolutionary Biology at Cornell University, Affiliate Faculty in the School of Aquatic and Fishery Science, University of Washington and former Science Envoy for Ocean Conservation (US State Dept). Her research on the health and sustainability of marine ecosystems has taken her from the reefs of Mexico, Indonesia, Palau and Hawaii to the cold waters of the Pacific Northwest and resulted in over 190 academic articles in journals such as *Science*, *Nature*, and *Ecology*. Her current research, based at Friday Harbor Laboratories, is focused on health of foundation and keystone species. She is a Fellow of the Ecological Society of America

and the American Association for Advancement of Science, and awarded the 2020 ESA Sustainable Science Award, 2020 Cornell SUNY Chancellors Award, 2019 Seattle Aquarium Conservation Research Award. Her award-winning books have garnered hundreds of reviews in top publications and won numerous awards: A Sea of Glass (2016) National Outdoor Book Award, Rachel Carson Environment Book Award, Honorable Mention and Smithsonian Top Books of 2016. Ocean Outbreak (2019) PROSE AWARD 2019, Ecological Society of America Sustainability Award 2019. She releases The Ocean Menagerie in April 2025. She serves on the Boards of Friday Harbor Marine Labs and Friends of the San Juans.

Dr. Jason Hodin is a larval biologist interested in metamorphosis and complex life cycles, particularly in sea urchins and sea stars. His research lies at the intersection of developmental biology, ecology and evolution, Since 2019, he has been running the first captive breeding program for sunflower stars at the University of Washington's marine biology center at Friday Harbor Laboratories, in partnership with The Nature Conservancy of California.

Dr. Elora López-Nandam is a Research Scientist in Invertebrate Zoology at California Academy of Sciences (CAS). She combines genomics with aquarium husbandry for important marine animals like corals and sea stars, in order to inform best practices for conservation breeding programs. This work is inherently collaborative and interdisciplinary, and key partners include Steinhart Aquarium at CAS, as well as Roatán Marine Park in Honduras.

Dr. Alison Moulding works in the NOAA Fisheries Southeast Regional Office as the recovery coordinator for Caribbean coral species listed under the U.S. Endangered Species Act. She provides scientific support for management actions and coordinates regulatory and recovery-related activities. Alison serves as the liaison between the Southeast Regional Office and the Acropora Recovery Implementation Team, a stakeholder group formed to implement the recovery plan for elkhorn and staghorn corals. She helps guide the team in prioritizing and implementing actions identified in the plan. She also participates in working groups of the Coral Restoration Consortium and is involved in developing guidance and products aimed at tracking and improving coral restoration success. Alison is a coral ecologist by training and prior to working for NOAA Fisheries, she worked as a research scientist at Nova Southeastern University where she studied coral reproduction, recruitment, and recovery from disturbance events.

Dr. Oliver Ryder serves San Diego Zoo Wildlife Alliance as the Kleberg Endowed Director of Conservation Genetics. He oversees research activities in the areas of molecular genetics, genomic studies, and genetic rescue efforts, including stem cell applications – all focused on reducing extinction risk and contributing to species recovery and sustainable populations. He guides the strategic development of efforts to develop and expand a global network of cryobanking facilities, especially for viable tissue culture cells as Chair of the newly formed Animal Biobanking for Conservation Specialist Group of SSC-IUCN. Oliver has contributed to key studies relevant to conservation management efforts for gorillas, California condors, black rhinos, Przewalski's horses, Anegada iguanas, bighorn sheep, and other species. He participates in developing studies that link conservation efforts for small managed populations of wildlife under human care with larger landscape scale efforts for wildlife populations in native habitat. He is co-organizer of the Genome 10K project with Stephen J. O'Brien and David Haussler and is a member of the Steering Committee for the Vertebrate Genome Project and a member of the Earth Biogenome Project. Oliver earned his bachelor's degree in Biology from the University of California, Riverside, and his doctorate in Biology

from the University of California, San Diego, where he now serves as Adjunct Professor in the Department of Evolution, Behavior and Ecology. Oliver is an AAAS fellow, recognized for contributions to understanding and conserving genetic diversity. His scientific achievements in animal health and species conservation have been recognized by the American Association of Zoo Veterinarians, and AZA. Oliver has been an early and consistent contributor to the development of conservation genetics and genomics and emerging efforts in genetic rescue using advanced genetic and reproductive technologies. His extensive bibliography includes several citation classics.

Dr. Lauren Schiebelhut is an evolutionary ecologist whose research focuses on exploring coupled ecological and microevolutionary responses spurred by perturbations to better understand population dynamics and responses to current and changing environments. She has 15 years of experience studying asteroids, other marine invertebrates, and macrophytes in coastal marine environments. Her research provides genomic insights, with relevant ecological context, to describe the eco-evolutionary dynamics in systems impacted by anthropogenic activities with an aim to use this information to help guide preventative, restorative, and adaptive conservation actions to increase resilience in the face of rapidly changing marine systems. Lauren earned her Ph.D. at the University of California, Merced and conducted postdoctoral research at UC Merced and UC Davis. She is currently faculty at Clovis Community College and working with the Sunflower Star Laboratory and UC Merced.

Dr. Neil Thompson is a Research Geneticist with the USDA Agricultural Research Service in Newport, Oregon. He leads the Pacific Oyster Genomic Selection project which is developing cost-effective methods for bringing genomic selection into lower-value aquaculture species and increasing survival against an oyster pathogen known to kill more than 90% of animals it infects. Before starting work in shellfish at the ARS, Neil researched the drivers of domestication selection in salmon and trout hatcheries, focusing on identifying the mechanisms that caused domestication and what traits were most impacted. This work occurred in multiple Pacific salmonids, included steelhead and Chinook salmon. Neil's research interests also include the genetic architecture of traits, most notably life-history expression in which he published research on how a major ecotype of migration timing in Chinook salmon is underlain by relatively simple Mendelian inheritance. This research has broad impacts within the Klamath River basin, where the majority of samples originated from, but extends range wide for conservation, restoration and management practices. His work is driven by an interest in aquatic systems and how anthropogenic actions can cause rapid adaptation to novel environments and systems.

Dr. Blake Ushijima is formerly from Hawai'i and received his Ph.D. at the University of Hawai'i at Mānoa in Microbiology working on bacterial pathogens that infect corals. His work focused on novel coral pathogens with an emphasis on the pathogen Vibrio coralliilyticus, which infects a variety of corals and marine invertebrates. He continued as a postdoc at Oregon State University working on bacterial oyster pathogens and probiotics. He was then awarded the George Burch Research Fellowship to work at the Smithsonian Marine Station studying stony coral tissue loss disease and was one of the lead investigators for the Coral Health and Marine Probiotics (CHAMP) Lab. During his time at the Smithsonian, he worked on developing probiotics to combat the outbreak of stony coral tissue loss disease (SCTLD) spreading throughout the Caribbean. In Fall 2020, he accepted an

Assistant Professor position at UNCW. His work focuses on the molecular pathogenesis of marine pathogens as well as their interactions with host-associated microorganisms.

Dr. Rebecca Vega Thurber is a Professor of Ecology, Evolution, and Marine Biology and the Director of the Marine Science Institute at UC Santa Barbara. Her lab investigates the role and dynamics of bacteria and viruses in marine hosts and habitats in order to better understand and mitigate or prevent the proximate causes of marine disease, habitat degradation, and ecosystem alteration. She has been a Senior Editor of the flagship journal *The International Society for Microbial Ecology Journal (ISMEJ)* and is now the Editor and Chief of the new fully free journal *Open Advances in Marine Biology*, *PeerJ*.

Dr. Robin Waples retired from NOAA Fisheries in Seattle as a Senior Scientist and remains an affiliate Professor at the School of Aquatic and Fishery Sciences, University of Washington. He has a B.A. in American Studies from Yale University and a Ph.D. in Marine Biology from Scripps Institution of Oceanography. His early research involved taxonomy and population genetics of marine shorefishes, but after moving to Seattle in 1986 much of his research focused on salmon. For over a decade, he led a group charged with developing the scientific basis for listing determinations and recovery planning for Pacific salmon under the U.S. Endangered Species Act. For ten years he also directed the Northwest Fisheries Science Center's Internal Grants Program, which provided over $2 million in seed-money grants for innovative research projects, especially by junior scientists. A major theme of Dr. Waples' research has been to apply evolutionary and ecological principles to real-world problems in conservation and management. Often this involves adapting standard population genetics models to better comport with life histories of actual species. Particular interests include: identifying conservation units; population genetics of high-gene-flow species; estimating effective population size; genetic interactions of captive and wild populations; genetic mixture/admixture analysis; evolutionary responses of natural populations to human-altered environments; interaction of population demography and evolutionary processes in species with overlapping generations. Dr. Waples is an elected member of the Washington State Academy of Sciences and the recipient of the 2018 Molecular Ecology Prize, among other awards.

Andrew Weltz is an Environmental Scientist in the California Department of Fish and Wildlife's Marine Region. Born and raised in San Jose, California, Andrew first developed an interest in marine science both through childhood visits to the Monterey Bay Aquarium and spending time in the ocean surfing in Santa Cruz and Capitola. After completing his bachelor's degree in biology at Humboldt State University, Andrew began his career with CDFW's Marine Region in Monterey in 2008, where he worked as a Scientific Aide on the Coastal Pelagic Species Project. This was also the beginning of his work as a scientific diver with CDFW's Diving Safety Program, an aspect of his job that over the years has allowed Andrew to contribute to Department efforts to manage the commercial market squid, recreational red abalone, and commercial herring fisheries, as well as commercial marine aquaculture and kelp forest ecosystems.

Dr. Jono Wilson is the Director of Ocean Science for The Nature Conservancy's California Chapter. His team operates across disciplines to address the world's most pressing ocean conservation challenges: restoration and recovery of habitats and species, elimination of overfishing, mitigation of wastewater and plastic pollution, and the protection of island ecosystems. His work is aimed at helping the Nature Conservancy and partners make informed conservation and management decisions to build and maintain resilience in the ocean. Jono is trained as a fisheries ecologist and

spent many years working with small-scale fishing communities to improve outcomes for nature and people. He continues to use a community-centered approach to conservation: developing partnerships, building trust, and supporting local actions to solve complex problems. Jono earned a Ph.D. from the University of California, Santa Barbara, where he also serves as an Adjunct Professor at the Bren School of Environmental Science & Management.

Appendix B: Details on Research & Uncertainties

Raw notes from workshop capturing group's ideas for future research efforts and key uncertainties to advance effective conservation breeding for SSWD resilience.

Action	Effort description (what, where, how)	Key uncertainties
All/most actions	• Start with a broad effort to bring in a diversity of animals from the wild and ensure they are distributed across facilities. • Screen animals collected in wild for disease to reduce transmission risk • Cryobanking (animals, microbiome, pathogen) • How to manage broodstock across facilities. What diversity we should bring in, what to target for cryobanking? Could leverage AZA network, work to align priorities. Identify other facilities to do challenge trials. • Continue to maintain shared database of sea stars in captive facilities (ZIMS) • Explore time needed for isolation (and interactions, e.g., temp dependent) • Identify multiple release locations, reference locations, source populations • Establish monitoring plan, coordinated across parties • Develop specific details for release strategies (e.g., number of individuals, life stages to raise and release) • Do best practices for priming animals for release • Monitor survival post-release • Talk to causative agent experts who study this sp. • Screen for causative agent across the west coast • Needs to be a research working group that work out the specifics of first research steps > coordinating with aquarists on how to keep them • Take stock of broodstock we have in aquaria and various facilities and target new collections to move into aquaria and cryopreservation - Can we use geographic region of stars as proxy for diversity initially? - Set up stars in ZIMS (Zoological	• What are best methods for reliable screening for disease? • Is there any survival after exposure, and under what conditions? • If we find resistance or tolerance, are they genetically linked? • How to scale up conservation breeding across facilities? • What is post-release survival of animals from breeding facilities? • Where will the water from the facilities go afterwards? • Can we test for acquired immunity?

Action	Effort description (what, where, how)	Key uncertainties
	Information Management System) - minimize number of generations in captivity (except to ID heritability) to reduce domestication / unwanted selection • Identify what our specific target will be for genetic diversity • Contextualize pathogen - which stars (other) species affected? - are there multiple strains and do they vary geographically / by species? - use past samples to test for presence • What did pre-wasting v. post-wasting samples look like (pathogen and microbiome)? • Continue to genetically characterize what stars are recruiting and persisting in CA and OR naturally (natural selection?).	
Translocations (reference option)	•	•
methods to maximize genetic diversity	• Always consider how to maximize diversity through backcrossing banked individuals • Always consider how to incorporate probiotics and Phage therapy into trials	
Challenge trials (pedigree-based genetic selection)	• Always consider how to maximize diversity through backcrossing banked individuals • Immune priming experiments with larvae • Always consider how to incorporate probiotics and Phage therapy • Incorporate additional stressors (O2, Temp, etc.)	• Which facilities have quarantine capacity right now? Alyssa's exp. • Which facilities have 2000 challenge trial capacity? Neil's exp.
Challenge trials (w/ genomic selection)	• Always consider how to maximize diversity through backcrossing banked individuals • Always consider how to incorporate probiotics and Phage therapy • Incorporate additional stressors (O2, Temp, etc.) • Immune priming experiments with larvae • Phage therapy • Immediate need is a quantitative genetic challenge study > the results of that are going to tell you heritability and how	

Action	Effort description (what, where, how)	Key uncertainties
	much variation from that facility's population, the likelihood of survival. That study will tell you is pedigree or genomic trials are worth it > makes sense to do it in more than 1 facility • Alyssa needs to see if any of the stars will survive different dosages of disease and under what conditions, establish minimum dose > figure out at what life stage they are susceptible to the disease	
Biotic treatments (probiotics)	• Screen other reservoir hosts (scallop) • Introduce treatments into challenge trials.	
Biotic treatments (phages)	• Explore literature/experts regarding any known phages for this causative agent	
Multi-action Strategy 1	• Manage and coordinate broodstock across all facilities. Where are the gaps and how do we ensure banking of all diversity. • Cryobank as much sperm across the range as possible. (Nicole Ravida?) • Tap into SAFE program expertise • Identify which facilities can do the challenge trials. • Strategy for managing broodstock across labs, document what is our founding gene bank, diversity catalog, gap analysis to prioritize what needs to be collected. • AZA have their own working group, we need to tap into their network and communicate our priorities, how can we fit those into their priorities • Make sure to collect data/samples/bank the pathogen too. • ZIM tracks animals in their database and keeps parentage in their data • GAP ANALYSIS • Change non-selective naming > this method will secure and preserve the gene pool • Build comprehensive plan • Identify multiple release locations, complementary reference sites where individuals already inhabit • Determine number of juvis outplanted	• Who is holding what? How many are in captivity, do we have their genetic logs? Are they cryobanked? • FH Labs does not have a liquid nitrogen freezer, in SD Zoo there are only 4 males that were preserved, now there are 50 males but they aren't cryopreserved • CA of Sciences only has juvis > don't need to have a liquid nitrogen freezer on site > thermos method in progress • Contact botanists who have worked on diseases that are 100% fatal in trees, there are similarities between the two situations • Contact people who are already studying the causative agent

Action	Effort description (what, where, how)	Key uncertainties
	• Determine number of adults to be kept in captivity • Develop plan to be introduced to legislators/department • Determine "release strategies" • Cryobanking is an essential first step regardless of other plans, capture that genetic diversity • Always swab for pathogen, keep log of strains • Research needs to be done on where the causative agent came from, is it local? Did it come from somewhere else? • Coordinating cryobanking, having one non selective methods facilities that hold and raises hundreds of stars, not touched by disease and no wild stars are brought in	
Multi-action challenge	Steps: 1. first Alyssa needs to hone in on dosage to make sure we don't kill all the animals. 2. Need to identify what is the earliest stage/age they are susceptible to the disease. 3. Quantitative genetic challenge study. Results will tell you heritability and how much variability form that pop there is for survival. This will tell you whether pedigree or genomic breeding will be possible. (20 full sib families – 100 animals; 2000 stars). Do this in multiple facilities because there will be differences.	Start with the big plan. Goals, Outplanting: reference sites, site prioritization, modeling to