Report of a Workshop to Assess Impacts of Climate Change on Sea Turtle Threats

Edited by Matthew D. Lettrich, Katrina Phillips, Chelsea Clyde-Brockway, and Blair P. Bentley

U.S. Department of Commerce
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With contributions and workshop participation from:
Julieta Alvarez Servín, Katia Ballorain, Chanel Browne, Liliana Colman, Francine Fiona Cousins, Tiffany Dawson, Niki Desjardin, Machel Donegan, Luciana Saraiva Filippos, Marc Girondot, Jimena Gutiérrez-Lince, Andrea Hernandez-Romero, Liyana Izwin Khalid, Claudia Leon, Robin LeRoux, Christopher Augustus Long, Laura Mary McCue, Horacio Merchant-Larios, Julia Merszei, Merope Sophia Moonstone, Miguel Veríssimo Morais, Dawson Pan, Joseph Pfaller, Trevor Lloyd Proctor, Matthew David Ramirez, Richard Reina, Liliana Areli Robledo Avila, Natalie Ann Robson, Daiane Santana Marcondes, Erin Seney, Debbie Sobel, Marylou Kay Staman, Alma Vázquez Gómez, and Matthew Ware

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U.S. Department of Commerce
Gina M. Raimondo, Secretary

National Oceanic and Atmospheric Administration
Richard W. Spinrad, NOAA Administrator

National Marine Fisheries Service
Janet Coit, Assistant Administrator for Fisheries

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Table of Contents

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Executive Summary

The effects of climate change on sea turtle populations have been well documented with examples of observed and projected impacts. However, how climate change interacts with other existing and possible future threats to sea turtles has received considerably less attention. At the 41st International Sea Turtle Symposium held 18 to 24 March 2023 in Cartagena, Colombia, we convened a half-day workshop entitled "The Climate-Threats Matrix: Understanding and Quantifying the Interactions of Cumulative Stressors with Climate Change and the Resulting Impacts on Sea Turtles" to explore the possible ramifications of climate change on non-climatic sea turtle threats and the potential downstream effects on populations.

On 20 March 2023, 38 professionals in sea turtle science, management, outreach, and education gathered to test a framework for assessing the impact of climate change on non-climatic sea turtle stressors. The framework began by identifying non-climatic stressors and designing conceptual models of the components that comprise those stressors. The framework then used expert elicitation to characterize how climate change may exacerbate or mitigate each component and the overarching stressor, as well as the uncertainty of each climate–stressor interaction based on their best current understanding.

Workshop participants walked through the elements of the framework in breakout sessions with each 3-4 participant group focused on a single sea turtle stressor. Participants provided feedback about each step in the framework. Critiques included requests for detailed examples for each step to guide the activity, clarifying language to improve the transition between framework steps, and additional time to build and explore the conceptual model, including time amongst other stressor groups.

Participant feedback will be used to refine the framework structure, activities, and interpretation. Following these updates, the framework will be ready to apply in a pilot implementation within a defined geographic region using regionally specific climate models and non-climate stressors, and engaging local sea turtle experts, pending agency and stakeholder priorities and resources.

Workshop participants, "The Climate-Threats Matrix: Understanding and Quantifying the Interactions of Cumulative Stressors with Climate Change and the Resulting Impacts on Sea Turtles" at the 41st International Sea Turtle Symposium, Cartagena, Colombia, 20 March 2023.

Introduction and Background

Sea turtle populations face threats, including climate change and other non-climate stressors, such as bycatch, coastal modification, disease, pollution, and marine debris (reviewed in Casale et al., 2018; Hamann et al., 2010; Fuentes et al., 2023; Nunes et al., 2021; Patrício et al., 2021; Rees et al., 2016; Wildermann et al., 2018). Climate change exposure is multi-faceted (e.g., changes in sea and air temperatures, rise in sea level, acidification of oceans, and alterations to cyclonic storm intensity and/or frequency) and is realized across a spectrum of spatial and temporal scales (Hawkes et al., 2009; Patrício et al., 2021). The direct effects of climate change on sea turtles have been the focus of recent research and represent a growing area of study (e.g., Jensen et al., 2018; Monsinjon et al., 2019; Patrício et al., 2019; Patrício et al., 2021). The effects of non-climate threats on sea turtles have received much attention historically, though variably by species and region (e.g., Bolten et al., 2011; Donlan et al., 2010; Fuentes et al., 2020a; Hamann et al., 2010; Hart et al., 2018). New threats continue to emerge as technology advances, human populations grow, and human behaviors evolve (e.g., Duncan et al., 2017; Goodale and Milman, 2016; Mashkour et al., 2020; Moore, 2008; Whittock et al., 2017).

Many of these threats to sea turtles have the potential to interact synergistically with each other (Crain et al., 2008; Fuentes et al., 2023; Piggott et al., 2015; Orr et al., 2020). For example, the effects of climate change are broad-reaching and will likely interact with most or all other non-climatic sea turtle stressors (Staudt et al., 2013), though the effect of climate change on other stressors and their combined downstream effect on sea turtle populations has received relatively little attention. Given the protected status of sea turtles (e.g., under the Endangered Species Act in the United States), the synergistic effects of climate change with non-climate stressors will add important components to conservation planning in a rapidly changing world (McClure et al., 2013; Seney et al., 2013). Understanding how direct and indirect stressors that impact sea turtle populations may vary at different spatial and temporal scales as the climate changes will be necessary to craft effective conservation strategies and will be an integral piece of the management response to climate change.

Climate Background

Anthropogenic climate change impacts all ecosystems, taxa, and ecological processes across the world. The impacts of climate change are expected to be particularly pronounced on sea turtle populations, as many aspects of their life history, physiology, and ecology are directly dependent on environmental conditions (Davenport, 1997; Hamann et al., 2010; Hawkes et al., 2009; Patrício et al., 2021). Further, sea turtles rely on terrestrial, coastal, and oceanic habitats on a global scale, making them vulnerable to habitat degradation across multiple spatial scales, with studies already demonstrating impacts across populations (Fuentes et al., 2020b; Hart et al., 2018; López-Mendilaharsu et al., 2020). The impacts of global climate change on the environment are multi-faceted, with many correlated climatic variables expected to result in interactive effects on sea turtle populations and with contemporary populations already demonstrating evidence of declines (Hawkes et al., 2009).

The most prominent and well-documented environmental impact on biological systems is the predicted rise in ambient air and sea surface temperatures over the next century. Under even the most conservative future climate projections, temperatures are expected to significantly increase relative to baseline conditions as are the frequency, duration, and severity of extreme heat events (IPCC 2023). Similar to temperature impacts, precipitation changes are expected, with some regions projected to experience much greater levels of rainfall than baseline conditions and others to experience a drying climate (Bacmeister et al., 2018; Montero et al., 2018).

Sea turtles possess a temperature-dependent mechanism of sex determination, whereby the sex of the developing embryo is dictated by the temperatures experienced within the nest during the incubation period (Yntema and Mrosovsky, 1980). The nest thermal environment is directly correlated with ambient air and sea surface temperatures, and rising temperatures are expected to lead to wide-scale rookery feminization, with studies already demonstrating this impact (Jensen et al., 2018). In addition to sex ratio shifts, increased nest temperatures result in higher embryonic mortality as embryos breach their critical thermal limits more often (Laloë et al., 2017) while also impacting hatchling morphology with higher incidence of malformations linked to temperature (Zimm et al., 2017). Similar to temperature, precipitation changes will also impact nest environments with decreases in rainfall in some regions expected to result in further warming of the nests and changes in soil moisture also impacting embryonic phenotypes, including sex (Lolavar and Wyneken, 2020).

Sea turtle nesting habitats are expected to be impacted by the effects of sea level rise and increases in storm events (Fuentes et al., 2010, 2019; Varela et al., 2018). The interplay between these variables will lead to an increase in both the number of nests that are inundated by sea water, as well as the number of nests that are washed out due to erosion as waves penetrate further inland (Fletcher 1992; Lyons et al., 2020; Martins et al., 2022; Ware et al., 2021). Nest inundations and washouts will inevitably result in higher rates of embryonic mortality.

While the impacts of climate change on nesting habitats are relatively well-studied, the impacts of climate change on turtles in the ocean are less clear. Temperature changes are expected to lead to changes in phenology and may result in higher predation rates of hatchling and juvenile turtles, while also changing their dispersal patterns as surface currents are altered (Hawkes et al., 2009). Changes in environmental conditions may impact food resources at all life stages as prey availability is altered, potentially resulting in trophic mismatches and negatively impacting growth and survival (Edwards and Richardson, 2004). These changes in prey availability may be influenced by changes in environmental conditions including temperature, ocean acidification, salinity, and dissolved oxygen, among others. In addition to directly impacting individual survival, such changes in resources and foraging can also have downstream effects that precipitate population declines by affecting how often females are able to nest (Reina et al., 2009), as well as the amount of resources allocated to reproductive outputs (e.g., yolk content, number of eggs per clutch, etc.).

Non-Climatic Stressor Background

A number of both natural and anthropogenic non-climatic stressors impact sea turtle populations to varying degrees depending on location and species. The biotic and abiotic drivers of non-climatic sea turtle stressors may shift as a result of an interaction with climate change, leading to synergistic impacts beyond those directly linked to climate. Building on previous summaries of threats to sea turtle populations (e.g., Fuentes et al., 2023; Mast et al., 2005; Wallace et al., 2011), the main stressors for the purposes of the workshop were predation, disease, pollution, marine debris, coastal development, marine development, vessel strikes, fisheries bycatch, and direct take. A comprehensive review of non-climate stressors is beyond the scope of this project; therefore, here, we present only high-level considerations for each stressor and illustrative examples of work related to the stressor.

Predation. On the nesting beach, eggs and hatchlings are predated upon by small mammals, crabs, birds, and insects (e.g., Heithaus, 2013; Lovemore et al., 2020; Marco et al., 2015). As hatchlings shift to the marine environment, bony fish and sharks join the list of predators. Predation risk decreases as sea turtles grow, though large sharks and jaguars target even mature individuals (e.g., Autar, 1994; Witzell, 1987). In addition to native predators, sea turtles are predated upon by introduced species including feral and domestic dogs and cats, and swine (e.g., Bevins et al., 2014; Gronwald et al., 2019; Ruiz-Izaguirre et al., 2015; Seabrook, 1989).

Disease. Diseases that impact sea turtles have been observed during all life stages and include bacterial, viral, and fungal species (e.g., Manire et al., 2017; Mashkour et al., 2020; Page-Karjian and Perrault, 2021; Smyth et al., 2019). We also consider parasites and disease vectors (e.g., Aznar et al., 1998; Chapman et al., 2019; Gordon et al., 1998; Greiner, 2013).

Pollution. Contributors to pollution include runoff and sewage discharge containing persistent organic pollutants and other contaminants, poor water quality caused by nutrient loading or subsequent harmful algal blooms, and oil spills (e.g., Arienzo, 2023; Camacho et al., 2014; Clukey et al., 2018; Keller, 2013; Vilca et al., 2018; Villa et al., 2017; Wallace et al., 2020).

Marine debris. We considered plastic pollution and marine debris as independent stressors from general pollution to focus separately on interactions leading to plastic consumption as well as entanglement in macroplastics and ghost fishing nets (e.g., Barnes et al., 2009; Colferai et al., 2017; Garrison and Fuentes, 2019; Kühn and Van Franeker, 2020; Schuyler et al., 2016).

Coastal development. Development activities along the coastline have resulted in hard infrastructure such as residences, hotels, transportation systems, beach access, and coastal protection and armoring (e.g., groins, seawalls, breakwaters, and floodgates). Coastal development also includes activities associated with coastal infrastructure such as beach driving, beach nourishment, light pollution, beach tourism, vegetation removal, and mechanical beach cleaning (e.g., Brock et al., 2009; Drobes et al., 2019; Kamrowski et al., 2012; Rizkalla and Savage, 2011).

Marine development. Infrastructure that interacts directly with the marine environment, such as offshore oil and wind platforms, ports, dredging, oil and gas mining, aquaculture, and in-water tourism, has the potential to affect sea turtles and sea turtle habitat during in-water life stages (e.g., Callier et al., 2018; Field and Gilbert, 2019; Goldberg et al., 2015; Hayes et al., 2017; Maxwell et al., 2022; Moore and Wieting, 1999; Putman et al., 2015; Schofield et al., 2021; Wallace et al., 2020; Whittock et al., 2017; Williams et al., 2022; Zerr et al., 2022).

Vessel strikes. A vessel strike could result from any interaction between a sea turtle and a vessel hull or propeller, including both commercial and recreational vessels (e.g., Barco et al., 2016; Field and Gilbert, 2019; Fuentes et al., 2021; Santos et al., 2018; Tyson et al., 2017). This category is related to, but considered separately from, marine development.

Fisheries bycatch. Any sea turtle captured as a non-target species in commercial, artisanal, or recreational fisheries may be considered bycatch. Fishing methods range from industrial longline vessels to individual hook and line, and a variety of net-based gear including purse seines, drift nets, and gill nets (e.g., Alfaro-Shigueto et al., 2018; Dodge et al., 2022, Lamont et al., 2022, Lewison et al., 2004, 2014; Peckham et al., 2007; Wallace et al., 2013). Entanglement in ghost gear is considered in the marine debris category.

Direct take. Direct take includes legal harvest in countries where it is permitted generally or for traditional use as well as illegal harvest and poaching (e.g., Barrios-Garrido et al., 2018; Humber et al., 2014; LaCasella et al., 2021; Nada and Casale, 2011; Quiñones et al., 2017; Vuto et al., 2019). Direct take differs from fisheries bycatch in that sea turtles are the target species.

A more in-depth discussion of the impacts of each stressor on sea turtle populations is included in Fuentes et al., (2023), and additional details for each species can be found in the IUCN Redlist[1] and in U.S. Endangered Species Act (ESA) status reviews[2] and five-year reviews[3].

Rationale for Workshop

During the 40th International Sea Turtle Symposium (ISTS40), held virtually in March 2022, Dr. Mariana Fuentes organized a virtual workshop entitled “Understanding and Quantifying Cumulative and Synergetic Stressors to Sea Turtles” about cumulative, additive, and synergistic effects of sea turtle stressors. In the months following the workshop, workshop participants produced a manuscript (Fuentes et al., 2023) and, through that process, identified a need to further explore the synergistic effects of climate change and non-climate threats to sea turtles.

To address those needs, we submitted a workshop proposal to the 41st International Sea Turtle Symposium (ISTS41) to build on the momentum and success from the 2022 workshop and focus on the cascading effects of climate change on other non-climatic sea turtle stressors. We proposed a workshop to include introductory presentations related to climate change and sea turtle threats followed by interactive breakout sessions using participatory assessment approaches. We welcomed participation from any region, education level, career level, species focus, and

[1] IUCN Redlist of Threatened Species. Available at https://www.iucnredlist.org/.

[2] U.S. Endangered Species Act (ESA). Status Reviews. Available at https://www.fisheries.noaa.gov/resources/all-publications?title=&field_category_document_value%5Besa_status_review%5D=esa_status_review&term_node_tid_depth%5B1000000045%5D=1000000045&field_species_vocab_target_id=&sort_by=created.

[3] U.S. Endangered Species Act (ESA). 5-Year Review. Available at https://www.fisheries.noaa.gov/resources/all-publications?title=&field_category_document_value%5Besa_five_review%5D=esa_five_review&term_node_tid_depth%5B1000000045%5D=1000000045&field_species_vocab_target_id=&sort_by=created.

occupational domain (e.g., research, management, education, outreach, and community organization).

We convened a workshop entitled "The Climate-Threats Matrix: Understanding and Quantifying the Interactions of Cumulative Stressors with Climate Change and the Resulting Impacts on Sea Turtles" at ISTS41 in Cartagena, Colombia on 20 March 2023. We summarize the workshop activities, outcomes, and future actions in this report.

Workshop Purpose and Goals

The purpose of the workshop was to explore the use of a framework to assess and characterize the effects of climate change on non-climate stressors to sea turtles with the ultimate goal of improving our understanding of the interactions between climate and non-climate factors. Specific workshop objectives included pilot testing the framework and associated processes in small breakout groups, identifying limitations of the framework, brainstorming improvements to the framework, and fostering a network of sea turtle professionals interested in the intersection of climate and non-climate stressors.

Proposed Framework

We proposed a framework to meet the goal of understanding the effects of climate change on non-climatic sea turtle stressors, which can inform dynamic responses to an unknown future. Our framework uses expert elicitation techniques, many borrowed from scenario planning (e.g., Borggaard et al., 2019, 2020; Butt et al., 2016; NPS, 2013), to harness the "wisdom of the crowd." Scenario planning uses a structured process to help decision-makers better prepare for the future. In general, scenario planning begins with identifying the critical driving forces and their uncertainty to produce a small number of plausible but divergent futures or scenarios. Then a series of tactics are developed that may help support or increase the chances that a preferred outcome or multiple outcomes, regardless of which scenario comes to fruition. Following the exercise, evaluations of these plausible scenarios can be made based on likelihood and certainty scales, and strategic plans, policies, and management plans can be updated to reflect this new information. This process helps identify priority funding allocation and actions.

We modified this framework to identify the current status of sea turtles and the current and future climate and non-climate stressors they face (current reality and processes). To estimate our "scenarios," we focused on specific drivers of each non-climate stressor and how that driver could potentially interact with elements of climate change. Finally, we characterized the impact and uncertainty of those interactions and finished by summarizing the interactions.

Framework Testing and Feedback

Workshop activities

We opened the workshop with three presentations to provide a common baseline of information for workshop participants. Matt Lettrich presented on climate exposure and the potential and observed impacts of climate change on sea turtles. Dr. Katrina Phillips presented non-climate threats to sea turtles based on those identified in the 2022 ISTS workshop "Understanding and Quantifying Cumulative and Synergetic Stressors to Sea Turtles" and the subsequent manuscript based on the discussions from that workshop (Fuentes et al., 2023). Dr. Matt Ware presented on urban pocket beach nesting (Sella et al., 2023) to provide an example of how a climate threat (i.e., sea level rise) may interact with a non-climate threat (i.e., coastal development).

We provided a brief overview of the proposed framework (see section "Proposed Framework" above) and a list of nine pre-identified non-climate threats (Table 1). Workshop participants identified "food web interactions" as an additional stressor and considered it in conjunction with the predation stressor. To prepare for breakout sessions, we set up stressor-specific stations around the room and instructed workshop participants to organize themselves into groups of 3 or 4 individuals per station.

Table 1. List of Predefined Non-Climate Sea Turtle Stressors and Associated Description.

Stressor	**Description**
Bycatch	Incidental capture in commercial and recreational fisheries
Direct take (harvest/poaching)	Intentional take of any life stage in-water or on beaches
Plastic/marine debris	Ingestion and/or entanglement in anthropogenic material, not including actively-used fishing gear
Coastal development	Construction, operation, maintenance, and other human activity in the terrestrial and near-shore environment
Marine development	Construction, operation, maintenance, and other human activity in the offshore environment
Pollution	Chemical contamination of water
Vessel strikes	Interaction with hull or propulsion system of all vessel size classes
Predation	Consumption of any life stage by native and non-native/invasive predators
Disease	Biological pathogens and parasites
Food web interactions[1]	
[1]The "food web interactions" was added by participants at the workshop.	

Breakout groups completed five activities, each with associated worksheets (Appendix C - Worksheets). The level of detail recorded on worksheets varied by group and by activity. As the intent of this workshop was to test and explore the capabilities and limitations of the framework, we have not shared the outputs of all of the groups in their entirety. In this section, we highlight examples of work produced by different groups and subsets of information compiled by all groups.

Activity 1: Identify non-climate stressors and develop concept map

In the first breakout activity, we asked participants to identify the drivers of their group's non-climate stressor (Fig. 1; see Appendix: Worksheets, Worksheet 1). From that list of drivers, we asked the groups to draft a conceptual model of how the drivers relate to the stressor and to the other drivers. For example, if the stressor was pollution, then potential drivers were population density, land use/streams/point and non-point sources nearby, etc. Groups used large sheets of paper and sticky notes to arrange and rearrange drivers to construct their concept maps (Fig. 2)

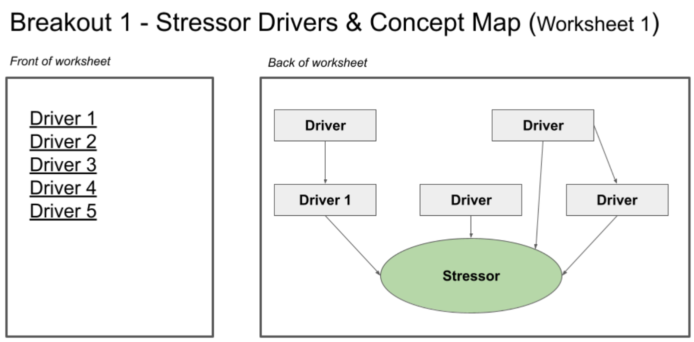

Figure 1. Simplified driver list and concept map.

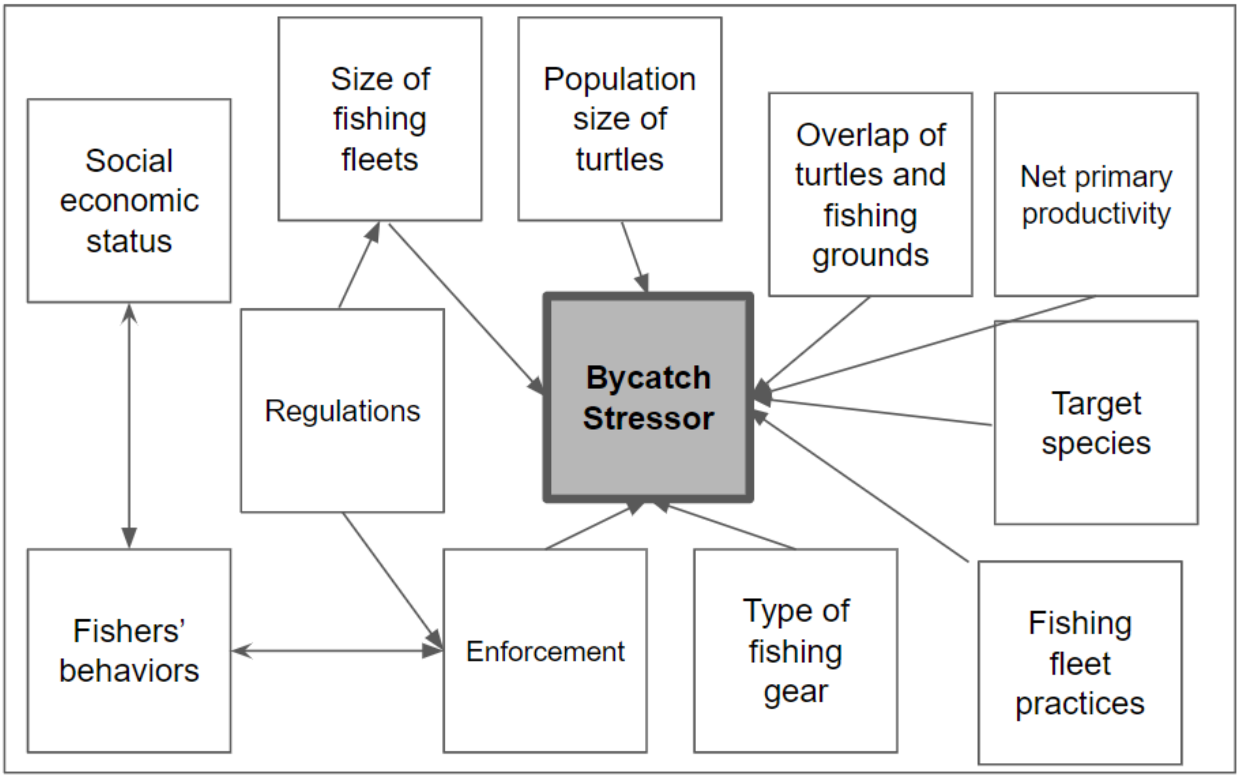

Figure 2. Sample conceptual model, bycatch stressor group. The bycatch stressor group identified a number of drivers that influence bycatch in sea turtles. This group opted to move directly into the use of sticky notes so as to move drivers around in a way that best allowed them to visualize the impact of drivers on the stressor and how these drivers interact with each other.

The outputs from Activity 1 (the list of drivers and conceptual models) served as the foundation for the activities that followed. Outputs identified in this activity also may be useful to direct attention to research and monitoring needs and to inform management decisions.

Activity 2: Climate–stressor matrix

In the second breakout activity, we asked participants to place the drivers they identified into a matrix with climate exposure factors (see Table 2). We asked the groups to narrow down their drivers to only those that are influenced by climate factors. The groups were given time to brainstorm interactions between the climate exposure factors and the driver of the non-climate stressor and were asked to write those possible interactions into the cells of the matrix (Fig. 3; see Appendix: Worksheets, Worksheet 2). For pollution, the driver "land use" includes things like agriculture and fertilizer use near streams. This driver interacts with climate change factors such as storms, precipitation, and sea level rise. These climate factors affect the amount of pollution that arises from different land use situations. Therefore, an interaction could be "agriculture and precipitation." Groups organized thoughts on a large paper matrix and recorded their potential interactions at the intersection of climate factors and stressor drivers (Table 3).

Table 2. List of Predefined Climate Factors and Associated Descriptions.

Climate Factor	Description
Sea surface temperature	Water temperature at the air–sea interface
Air temperature	Air temperature at the air–sea interface
Precipitation	Amount, timing, duration, and type of precipitation
Storms	Number, frequency, intensity, and tracks of storm systems
Sea level rise	Relative elevation of sea level; should be considered jointly with land elevation change
Ocean pH	Changes in oceanic pH related to carbon cycle
Salinity	Changes in sea surface salinity related to evaporation, precipitation, and runoff
Dissolved oxygen	Changes in dissolved oxygen related to temperature, mixing, and biological consumption

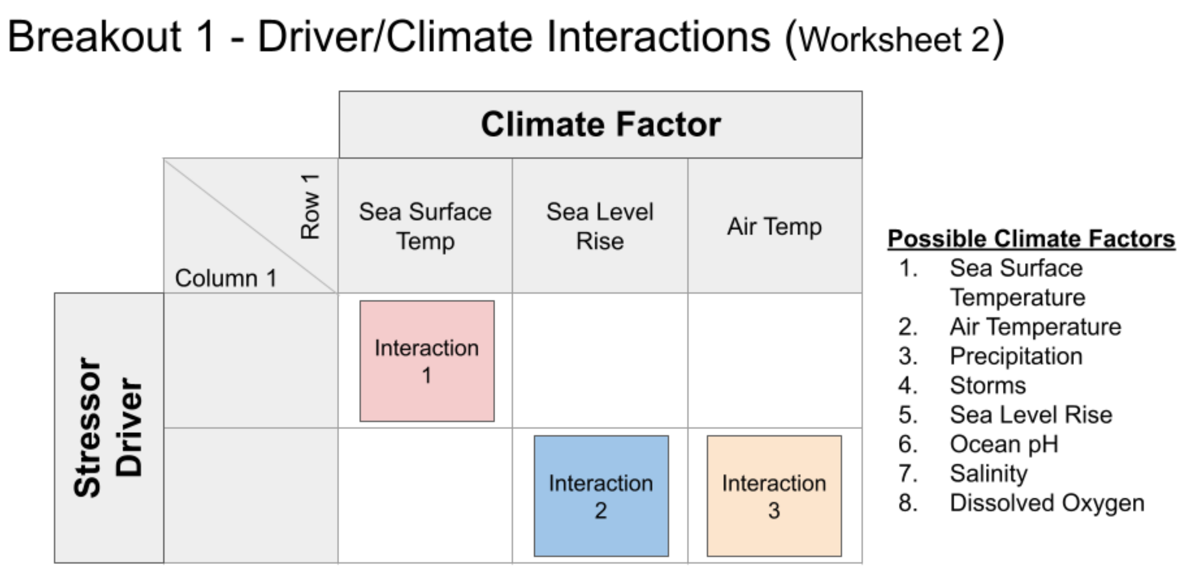

Figure 3. Simplified climate factor–stressor driver matrix.

Table 3. Climate factor–stressor driver matrix, coastal development stressor group. The group identified interactions relating to which climate factors cause humans to modify their area use and behavior. This table reflects only brainstorming during the workshop and should not be considered complete, comprehensive, or accurate for any specific region or species.

		Climate Factor		
		Sea Level Rise	**Storms**	**Precipitation**
Coastal Development: Stressor Drivers	Tourism	• Shifts in locations people go to • Force hotels, etc. to reinforce their properties	• Decrease number of tourists	• Force reinforcement • Decrease number of tourists
	Increasing coastal human population	• Gentrification	• Gentrification • Migration from rural communities to the coast	• Gentrification
	Recreation	• Similar to Tourism interactions • Shifts in type of recreation • Change in diving/snorkeling recreation	• Similar to Tourism interactions • Could destroy access to recreation areas • Increased beach nourishment	• Similar to Tourism interactions
	Economic conditions	• Complete or major loss of coastal areas (or entire islands)		
	Access and resources			
	Policy	• Enactment of SLR policy • Increased requirement to use nature-based solutions	• Issuance of emergency orders without normal environmental regulations • Increasing or decreasing incentive to rebuild in place	
	Trade/ Commerce		• Potentially have to rebuild ports • Rerouting shipping to different methods	

In Activity 2, the interactions can be used to seed hypotheses and identify areas of future research. When comparing the interactions identified in the matrix to a literature review, knowledge gaps can be identified and prioritized.

Activity 3: Impact evaluation

It is not enough to determine if there is a relationship between the driver of a stressor and a climate factor; we must classify whether these drivers have a low or high impact on the stressor and whether the climate factor has a low or high impact on the driver. In the third breakout activity, we asked participants to place the interactions identified in Activity 2 along two separate axes: 1) the impact of the driver on the stressor and 2) the impact of climate on the driver (Fig. 4; see Appendix: Worksheets, Worksheet 3).

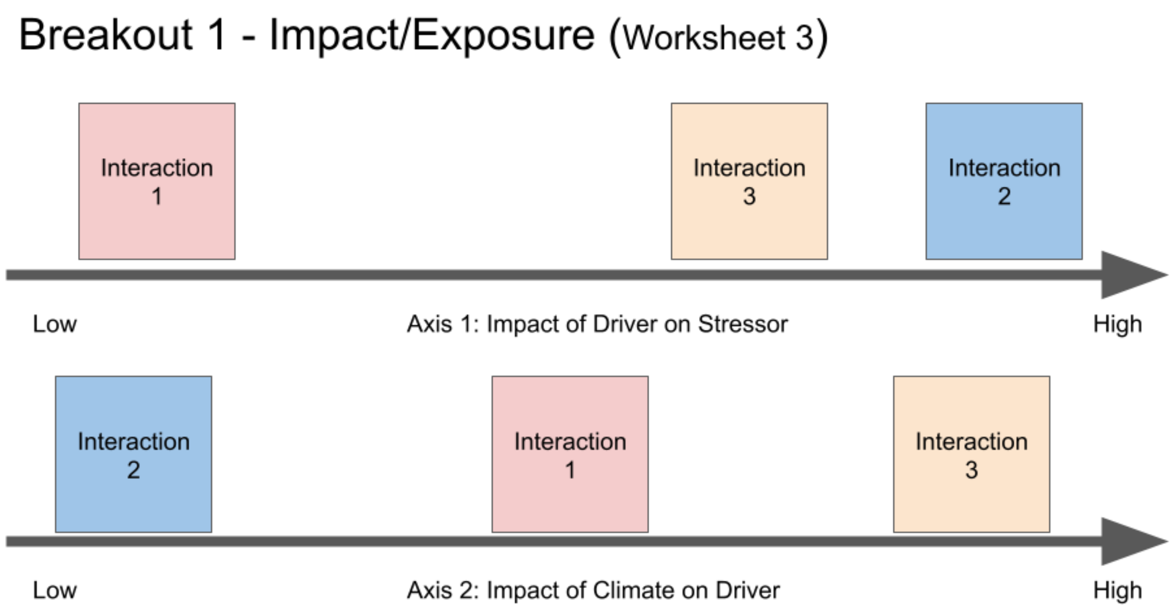

Figure 4. Two axes of impact: impact of driver on stressor and impact of climate on driver.

Activity 4: Impact plotting

In the fourth breakout activity, we asked participants to arrange the axes from Activity 3 in a two-dimensional space, with the impact of the driver on the stressor along the vertical axis and the impact of climate on the driver along the horizontal axis (Fig. 5; see Appendix: Worksheets, Worksheet 4). Participants placed the interactions in the two dimensional space based on their positioning along the axes in Activity 3. For example, with the pollution stressor, an interaction "agriculture intensity and sea level rise" would be placed in the upper left quadrant because agriculture has a large impact on pollution, but sea level rise has a low impact on agricultural intensity (at least generally, specific contradictory examples can be found such as ocean inundation of areas along shorelines). Breakout groups used sticky notes to arrange interactions within the two-dimensional space (Fig. 6).

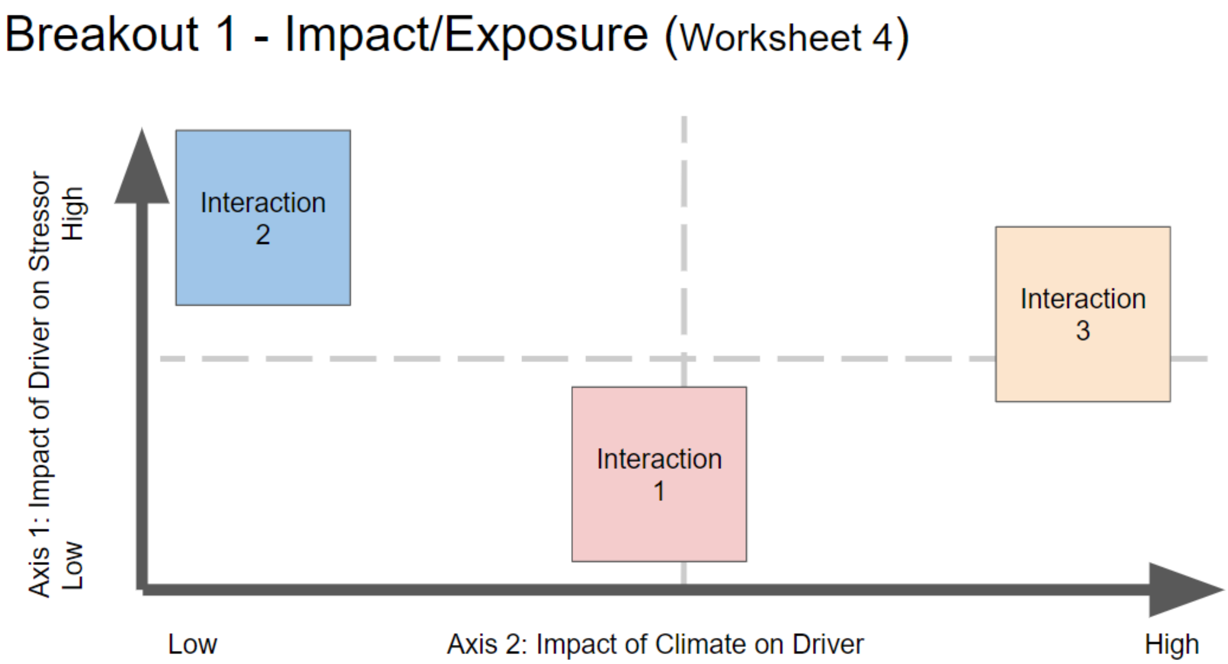

Figure 5. Simplified impact–impact plot.

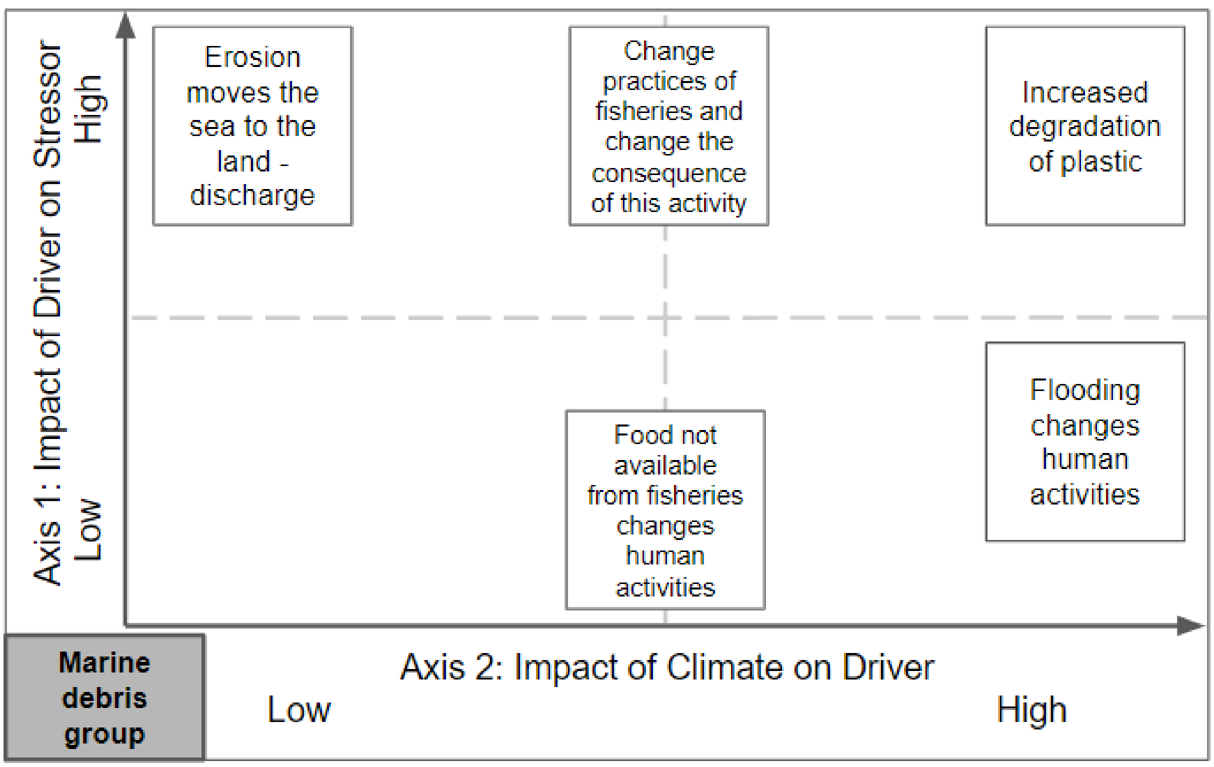

Figure 6. The impact–impact plot, plastic and marine debris stressor group. The plastic and marine debris stressor group identified, for example, that increased degradation of plastic had a “high” impact on plastic pollution and that climate factors had a “high” impact on the degradation of plastic. As such, this interaction was placed in the top right quadrant. This figure reflects only brainstorming during the workshop and should not be considered complete, comprehensive, or accurate for any specific region or species.

The impact–impact plot populated in Activity 4 can be divided into quadrants, with the top right being interactions that are most impactful on the population and most impacted by climate change. These would be interactions that require the most urgent attention as climate conditions change. Interactions in the top left represent those that are important to the population but not highly relevant to climate change. These would be interactions that need to be addressed for species conservation but not necessarily from a climate perspective. Those interactions in the bottom right are highly affected by climate but not currently highly impactful to the population. These would be interactions to monitor for changes. Finally, interactions in the bottom left represent those that are the least affected by climate change and the least impactful on the population. These would be interactions that are low priority for species conservation and climate management.

Activity 5: Certainty plotting

In the fifth and final breakout activity, we asked participants to consider the certainty of an interaction occurring and plot interactions in a two dimensional space with the impact of the driver on the stressor on the vertical axis and the certainty of the interaction occurring on the horizontal axis (Fig. 7; See Appendix: Worksheets, Worksheet 5). Here, groups estimated the relationship between the impact of the interaction and how likely this interaction is to take place. For example, with the interaction of "agriculture and precipitation," the impact on the stressor (pollution) is high, and the certainty is high. Every time there is precipitation, there is increased agricultural runoff into streams/ocean. A low-certainty interaction would be the interaction of agriculture and sea level rise. Breakout groups organized their interactions in a two dimensional space using a large sheet of paper (Fig. 8).

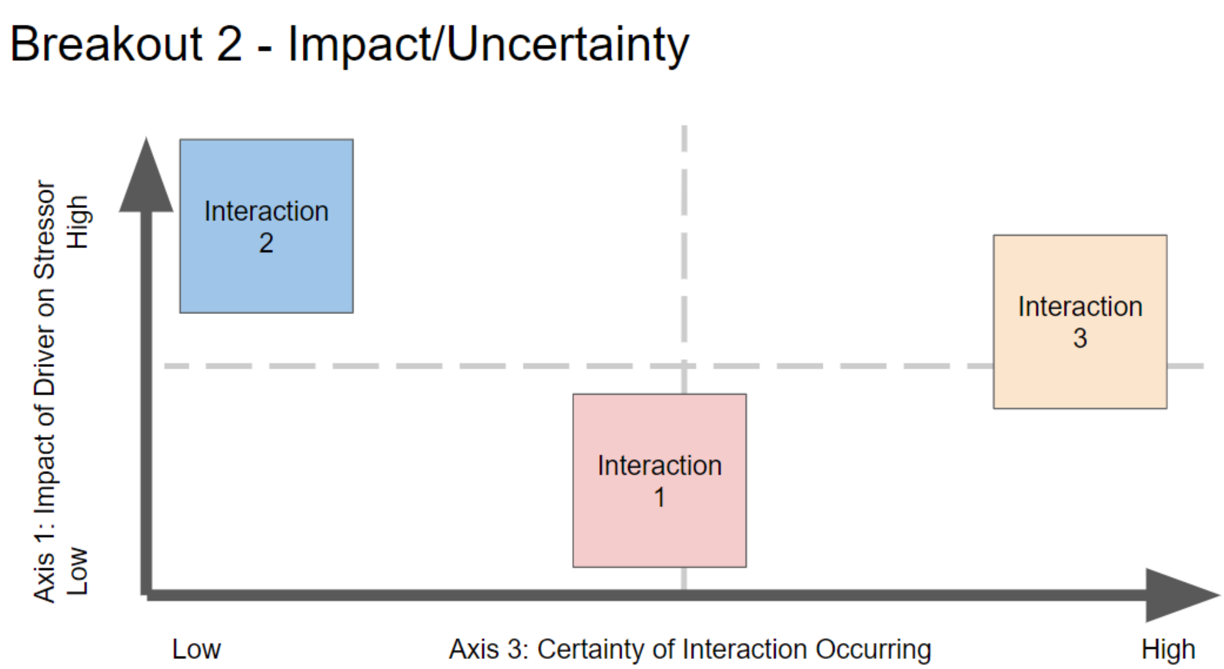

Figure 7. Simplified impact–uncertainty plot.

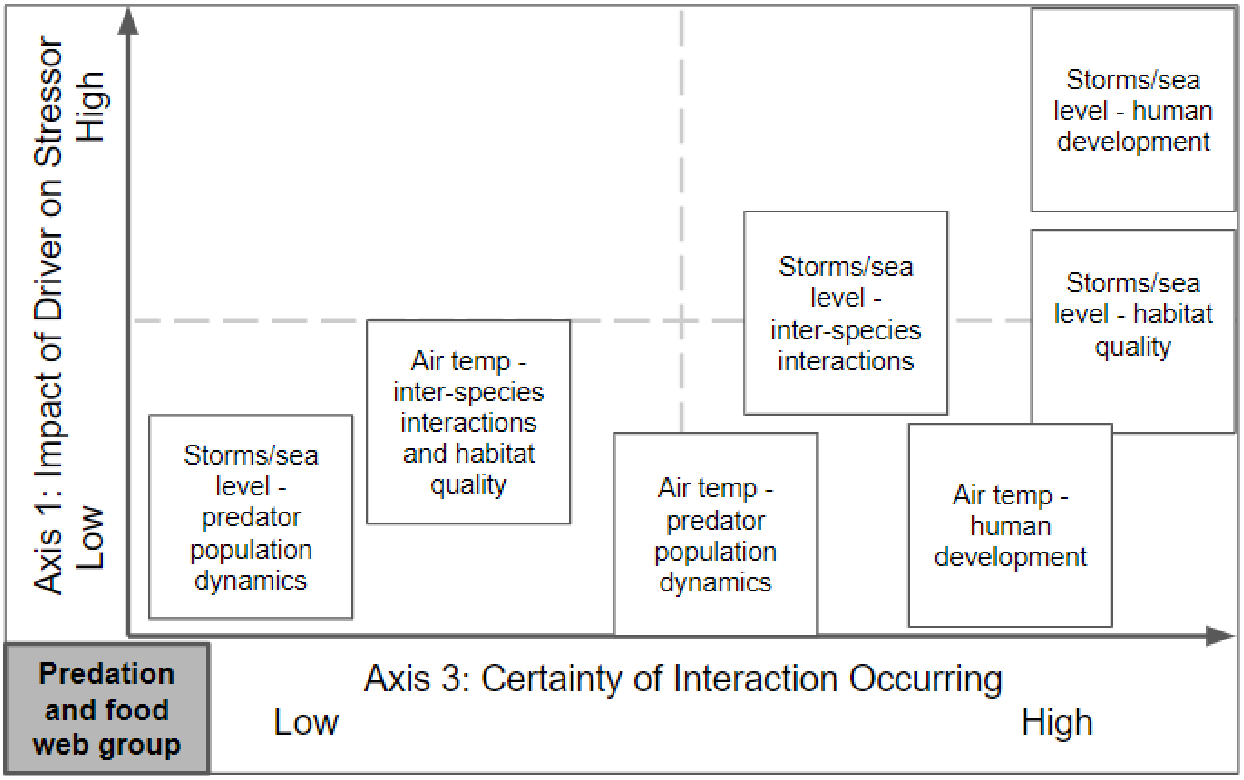

Figure 8. The impact–uncertainty plot, predation and food web group. The predation and food web group predicted that while storms/sea level and habitat quality had a "high" impact on terrestrial predation and a "high" certainty of the interaction occurring, other interactions such as air temperature and predator population had a "low" impact on terrestrial predation and a "moderate" likelihood of occurring. This figure reflects only brainstorming during the workshop and should not be considered complete, comprehensive, or accurate for any specific region or species.

Similarly to the impact–impact plot in Activity 4, the impact–uncertainty plot in Activity 5 can be divided into quadrants, with the top right being interactions that are most impactful on the population and certain to occur. These would be interactions that require the most urgent attention as climate conditions change. Interactions in the top left represent those that are important to the population but where the direction and magnitude of the interaction are less certain. These would be interactions that could be further explored through directed research investment and/or using exercises like scenario planning. Those interactions in the bottom right are highly certain as not currently highly impactful to the population. These would be interactions to monitor for changes in impact to the population. Finally, interactions in the bottom left represent those that are the least impactful on the population and highly uncertain. These would be interactions that are low priority for species conservation and climate management.

Report-out themes

Information was produced during each of the activities, recorded on the worksheets, and combined in a common all-group wall-mounted display used during report-outs. Through the report-outs, participants shared feedback about the framework and the process, and we discussed potential ways for the information they produced to be interpreted and used.

Participants highlighted the importance of completing the first activity in a comprehensive, detailed, and accurate manner. With so much of the rest of the activities relying on the first activity, participants would have liked to have seen additional guidance, concrete examples, and time to complete the activity. Relatedly, providing workshop participants an illustrative example would have been helpful to guide the first activity (and possibly succeeding activities). For future implementation, providing one stressor as an example may be helpful. Narrowing the focus of each stressor would also have been helpful. It was difficult to generalize across regions, and some stressors had multiple components (e.g., offshore development could include oil/gas energy, renewable energy, mining, maritime infrastructure, and permanent aquaculture). Participants noted a tendency to go down "rabbit holes" and, without clear boundaries, were unsure how far to go.

Participants noted that terminology needed to be introduced and agreed upon to better facilitate discussion. For example, the terms "stressor" and "driver" were not intuitive to all participants, and without a common understanding of the terminology, breakout discussions could easily be taken off track. There was some confusion surrounding the inclusion of specific drivers, particularly in deciding whether to include actions that could be a contributor to the stressor and actions that could serve as a solution to the stressor.

Participants noted that special consideration needs to be given to the different life stages (e.g., egg, hatchling, juvenile, or adult) because the effect of a stressor may vary between life stages. Likewise, the interaction of climate change factors on a stressor may differ between life stages.

The timeframe of consideration is important to define, as some participants found a desire to base decisions on current understanding of stressors, while other participants wanted to include projected or predicted levels of stressors. When completing this exercise as presented for framework exploration and testing, participants made tradeoffs in their considerations of temporal and spatial scales. It is unclear whether those tradeoffs would transfer to a regional or local implementation in which temporal and spatial scales would be predefined during project scoping.

Participants asked where the impact of policy may be considered in the framework. Policy decisions and implementation may serve to lessen or exacerbate the effects of climate change on a stressor.

Finally, participants discussed the challenge of preparing for unknown interactions. The exercises throughout the activities dealt with real and imagined interactions, and participants expressed a need for identifying and quantifying currently unknown interactions as they present themselves.

Summary, Recommendations, and Next Steps

Overall, feedback from participants was positive regarding the workshop organization, communication, and activities. Participants provided constructive suggestions to improve the experience if the workshop were to be offered again in the future. Participants enjoyed the interactive and collaborative nature of the workshop and its activities.

In general, a longer workshop (e.g., full-day) would have been beneficial. Groups expressed a need for additional time to complete the first activity, identifying stressor drivers and drafting the conceptual model, which would have provided a stronger base for the remainder of the activities. We heard a desire for increased time during report-outs for participants to hear about the findings and results from other groups. Relatedly, participants also expressed a desire to move between stressors during the workshop as their interests included multiple stressors.

The framework could be improved by clarifying definitions, narrowing the focus of stressors, providing more comprehensive stressor background information (e.g., literature review), and engaging targeted audiences for each stressor. These suggestions provided by participants will be used to update and refine the framework. Following those updates, the framework will be ready to use in a pilot implementation within a geographic region. When selecting a geographic region for pilot implementation, consideration should be given to areas that already have robust research and monitoring of non-climate stressors, a sizable base of expertise (e.g., researchers, managers, and educators), and readily available climate change projections at management-relevant scales.

Applying this framework within a geographic region will provide insight into cascading effects of climate change and novel interactions between climate conditions and non-climate threats to sea turtles, thereby improving the potential to understand, manage, and conserve sea turtle populations.

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Appendix 1: Agenda

Time	Duration	Activity
1:30–1:40	10 min	Intros Housekeeping Goals/Objectives Framing
1:45–2:15	30 min	Presentations: 1) Climate and sea turtles overview (Matt Lettrich) 2) Sea turtle stressor overview (Katrina Phillips) 3) Climate impact on stressors (Matt Ware)
2:15–2:25	10 min	Framework Proposal
2:30–3:45	75 min	Breakout Groups: 1) Icebreaker 2) Brainstorm stressor drivers/concept map (Worksheet 1) 3) Brainstorm driver interactions with climate variables (Worksheet 2) 4) Map to driver impact vs exposure impact plot (Worksheet 3) 5) ID high-impact combinations (Worksheet 4)
3:45–4:00	15 min	Break
4:00–4:30	30 min	Report-outs
4:30–5:00	30 min	Breakout Groups: 1) Map driver/exposure combos to impact/uncertainty plot (Worksheet 5) 2) Develop summary statements
5:00–5:15	15 min	Report-outs
5:15–5:30	15 min	Recap and Next Steps

Appendix 2: Workshop Participants

Julieta Alvarez Serví-n, Universidad Nacional Autónoma de México

Katia Ballorain, Centre d'Etude et de Découverte des Tortues Marines

Blair Bentley, University of Massachusetts Amherst & University of Western Australia

Chanel Browne, MOC Marine Institute

Chelsea Clyde-Brockway, Leatherback Trust

Liliana Colman, Centre for Ecology and Conservation, University of Exeter

Francine Fiona Cousins, Alligator Head Foundation

Tiffany Dawson, University of Central Florida

Niki Desjardin, Ecological Associates, Inc.

Machel Donegan, Alligator Head Foundation

Luciana Saraiva Filippos, Oceanographic Institute of the University of São Paulo

Marc Girondot, Laboratoire Ecologie, Systématique, Evolution - Université Paris Saclay, CNRS, AgroParisTech

Jimena Gutiérrez-Lince, Sea Turtle Program, Department of Environment, Cayman Islands Government

Andrea Hernandez-Romero

Liyana Izwin Khalid, Marine Research Foundation

Claudia Leon, Centro Ecológico Akumal

Robin LeRoux, NOAA Fisheries, Southwest Fisheries Science Center

Matthew Lettrich, ECS Federal in support of NOAA Fisheries

Christopher Augustus Long, University of Florida

Laura Mary McCue, NOAA Fisheries

Horacio Merchant-Larios, Universidad Nacional Autónoma de México

Julia Merszei, Lotek Wireless Inc.

Merope Sophia Moonstone, University of Central Florida's Marine Turtle Research Group

Miguel Veríssimo Morais, Projecto Kitabanga - Universidade Agostinho Neto/Faculdade de Ciências Naturais

Dawson Pan, ProTECTOR, Inc.

Joseph Pfaller, NOAA Fisheries, Southeast Fisheries Science Center

Katrina Phillips, University of Massachusetts Amherst

Trevor Lloyd Proctor, Purdue University Fort Wayne

Matthew David Ramirez, University of North Carolina Wilmington

Richard Reina, Monash University

Liliana Areli Robledo Avila, Facultad de Agronomía y Veterinaria, Universidad Autónoma de San Luis Potosí

Natalie Ann Robson, Charles Darwin University

Daiane Santana Marcondes, Universidade Federal do Paraná

Erin Seney, University of Central Florida

Debbie Sobel, Sea Turtle Conservation League of Singer Island

Marylou Kay Staman, NOAA/Cooperative Institute for Marine Atmospheric Research

Alma Vázquez Gómez, Universidad Nacional Autónoma de México

Matthew Ware, University of North Carolina Wilmington

Appendix 3: Worksheets

Worksheet 1 Stressor ___________________ Group # __________

Stressor conceptual model: What drives the stressor?

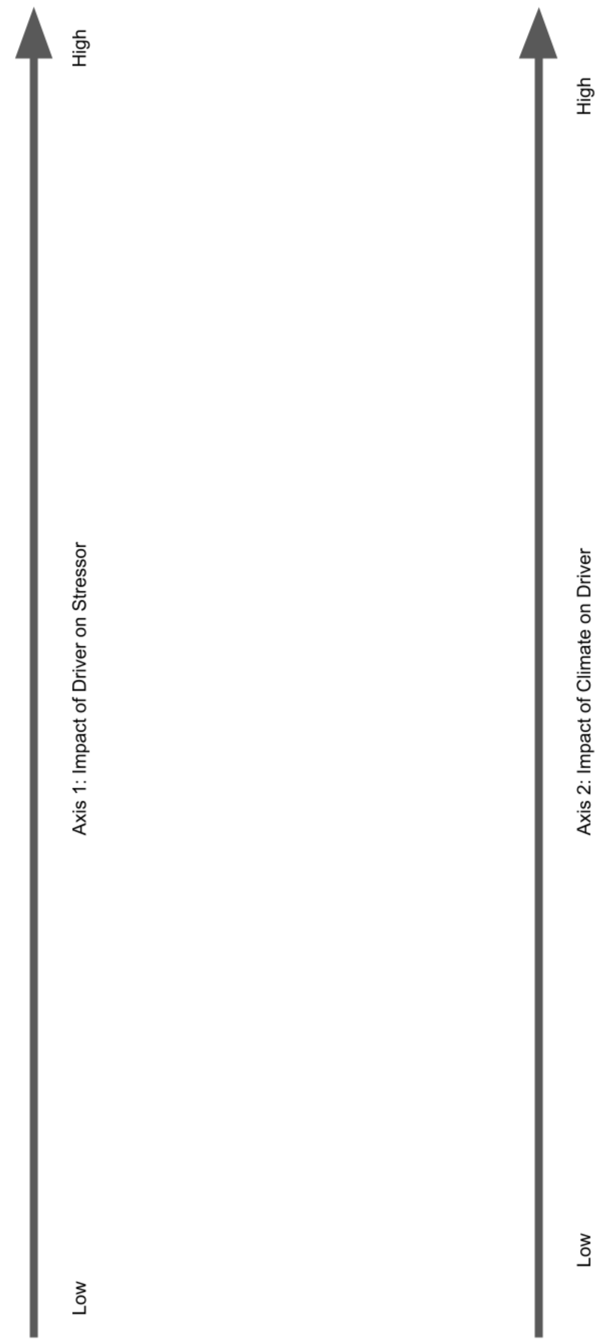
Worksheet 2 Stressor ___________________ Group # __________

Instructions: Populate Column 1 with the Drivers identified in Worksheet 1
Populate Row 1 with Climate Factors
Brainstorm possible ways that the Climate Factor will affect the Driver and write that in the intersecting cell

		Climate Factor				
	Row 1 / Column 1					
Stressor Driver						

Worksheet 3 Stressor ___________________ Group # __________

Instructions: Write each of your "Interactions" (cells on Worksheet 2) on a Post-It note
Place the Post-It note along the spectrum



Worksheet 4 Stressor ___________________ Group # __________

Instructions: Write each of your "Interactions" (cells on Worksheet #2) on a Post-It note
Using results from Worksheet #3, place a new Post-It note on the plot below based on Axis 1 and Axis 2

Worksheet 5 Stressor ___________________ Group # __________

Instructions: Write each of your “Interactions” (cells on Worksheet #2) on a Post-It note
Using results from Worksheet #3 for Axis 1 and your own interpretation for Axis 3, place a new Post-It note on the plot below