Climate Scenario Working Group

What is climate change?

Climate change refers to the long term change in temperatures and weather patterns throughout the planet (UN). This has happened naturally over >1000 year cycles in the earth's past. However, since the industrial revolution, humans have been adding high levels of greenhouse gases (gases such as CO2 that trap heat) into our atmosphere. The planet has warmed over 2 F (1.2 C) and the oceans have acidified since the industrial revolution, which has already caused issues across the globe, including: observed range shifts in fished species (Fauchald et al., 2021), effects on recruitment (e.g., Pierre et al., 2018), and changes in fish biology (e.g., Frommel et al., 2016; McKenzie et al., 2021).

How is climate change already affecting the Pacific Islands?

Increases in temperature have had some pronounced effects on the nearshore reef systems of Pacific Islands and have the potential to shift the distribution of our most important pelagic predators, including fished species. In Hawai'i, waters have warmed nearly 1 F (0.5 C) in the past 100 years, with annual temperature in the late 2010s reaching record highs (Figure 1a). While temperatures around Hawai'i naturally fluctuate on decadal scales from processes such as the Pacific Decadal Oscillation and North Pacific Gyre Oscillation, the background warming coupled with these natural cycles led to record highs.

In the Marianas archipelago, waters have warmed around 1.6 F (0.9 C) in the past 100 years, with 2021 reaching record highs and surface water temperatures averaging nearly 86 F (30 C; Figure 1b). In American Samoa, regional waters have warmed nearly 1.4 F (0.8 C) over the past century, with the record high occurring in 2024. The pronounced warming in these regions has led to concern for their fish resources, especially those nearshore.
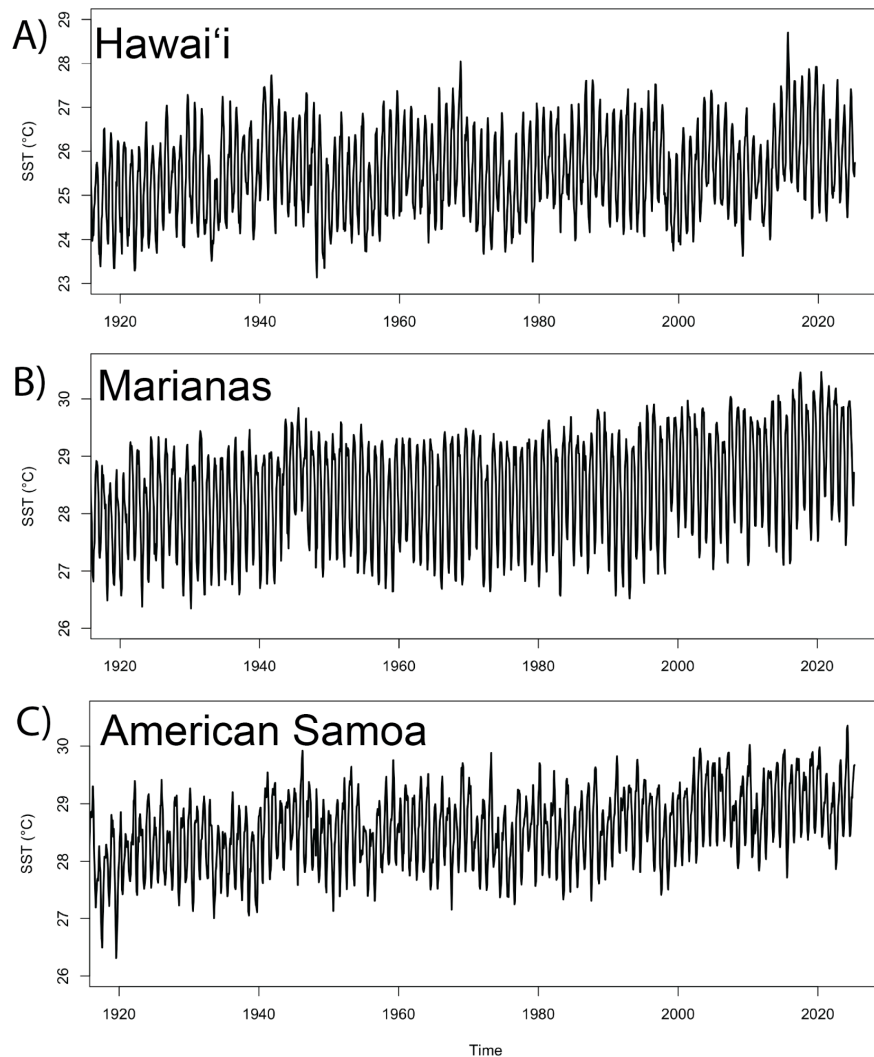
Figure 1: Reconstructed sea surface temperature estimates around Hawaiʻi(A), the Marianas (B), and American Samoa (C) for the past century. Data: NOAA Extended Reconstructed SST V5.

How do we expect climate change to affect the Pacific Islands in the future?

This depends on the pathway we choose to partake in as a society. Climate researchers have historically used Representative Concentration Pathways (RCP) that focus on different scenarios of carbon dioxide emissions through the end of the 21st century. Recently, the focus has shifted to center on Shared Socioeconomic Pathways (SSPs). These may have similar carbon dioxide emissions as RCPs, and thus similar warming scenarios, yet SSPs also explicitly account for various social drivers that lead to different emission regimes. The details of these SSPs can be found here:

https://climatedata.ca/resource/understanding-shared-socio-economic-pathways-ssps/.

In the Pacific Islands, expected warming trends vary by region, with the most northern domain, Hawai'i, having the greatest overall expected warming by the end of this century of the major jurisdictions (Figure 2a,d). By comparison, the Marianas Archipelago and waters surrounding American Samoa are expected to experience moderate future warming (Figure 2 b,c,e,f). Warming rates in each region vary substantially based on emissions scenario, with SSPs corresponding to 8.5 level emissions scenarios ('business as usual', high emissions) resulting in nearly double the warming rate as moderate emissions (i.e., SSP 4.5; Figure 2).

How will warming affect fish and fisheries in the Pacific Islands?

Warming rates will affect fish and fisheries differently among regions based on the habitat and life history of the targeted fisheries species, in addition to the mobility of the fishers. For nearshore ecosystems, corals that serve as the foundation of the habitat for reef fishes are expected to bleach and die within the coming decades (McKay et al., 2022.; Hoegh-Guldbeg et al., 2023, though see Klein et al., 2024 for uncertainty around this projection). This could lead to the potential for mass habitat loss throughout the Pacific Islands. This is of particular concern in the warmest regions, such as Guam and American Samoa. Coral reef fishes are the least mobile of the fishery-targeted species in the Pacific Islands, and thus are perhaps most at risk (Collins et al., 2024; Welsh et al., 2013).

For pelagic species, such as the targets of the Hawai'i and American Samoa longline fisheries, the effects are a bit less clear. For surface feeding pelagic predators, such as yellowfin tuna (*Thunnus albacares*), skipjack tuna (*Katsuwonus pelamis*), and mahimahi (*Coryphaena hippurus*), scientists have begun to estimate changes in distribution based on relationships to SST and primary production (Lehodey et al., 2008; Senina et al., 2020). Further, researchers are continuing to work on updating and modifying these projections to be at the spatial and time scales most relevant to fishers in the Pacific Islands. The near-surface feeding behavior of these species give scientists more confidence in the projections of their movements by the end of the century. Specifically, we expect yellowfin tuna and skipjack tuna to decrease in overall stock size and the centers of their distribution are expected to shift eastward, potentially reducing availability to western Pacific Island nations (Bell et al., 2021).
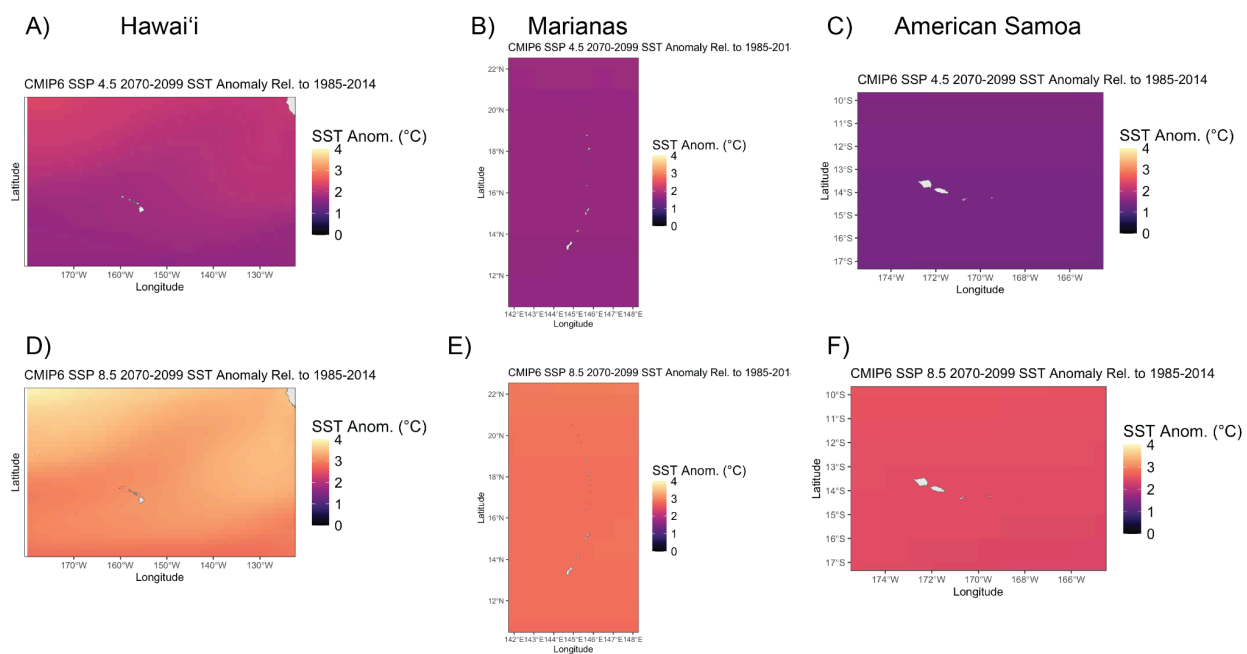
Figure 2: Expected sea surface temperature anomalies under SSP 4.5 (A-C) and SSP 8.5 (D-F) for Hawaiʻi (A,D), the Marianas (B, E), and American Samoa (C,F).

However, several species that large fisheries target in the Pacific Islands are mesopelagic foraging fishes, meaning they feed at depths between 150-400 m during the daytime and rise closer to the surface at night. These species include bigeye tuna (*Thunnus obesus*), albacore (*Thunnus alalunga*), and swordfish (*Xiphias gladius*). Our confidence and ability to predict shifts in the distribution of these species is often limited by our understanding of their behavior when they are at their daytime depths, including their sensitivity to subsurface temperature and oxygen. This limited understanding is further amplified by uncertainties in subsurface temperature and oxygen estimates in our climate model projections. Unlike surface waters, properties of subsurface waters are affected by their age (i.e., how long it as has been since that water was at the surface), locations of their formation (i.e., where the water from the surface was pushed subsurface), and processes occurring in the water above the subsurface waters. The latter concern is particularly relevant when it comes to oxygen, where bacterial consumption of dying material in the surface ocean leads to reduced subsurface oxygen. If this process is pronounced, it can lead to the removal of enough subsurface oxygen such that species like bigeye tuna are unable to forage at depth.

Bottomfish are perhaps our least understood group of fishes regarding sensitivity to climate change. These species inhabit moderately deep waters near areas with steep changes in depth throughout the Pacific Islands. The physical properties of subsurface waters where these species live can be particularly hard to observe and model, leading to uncertainty about the present drivers and limitations of their habitat. These regions also require computationally expensive downscaled climate projections to begin to understand how subsurface properties are likely to change in bottomfish habitat by the end of the century. The survival of their larvae, which often occupy shallower water, may be affected by warming oceans. Indeed, studies have suggested changes in wind patterns may affect recruitment in a Hawai'i bottomfish species. However, we presently manage most of these species as a complex and know very little about their early life history, leaving us with little information on how recruitment of these species may be affected by a warming climate.

How, and should, this information be used in stock assessment and management?

In the U.S. Pacific Islands region, the WPRFMC and NMFS are responsible for setting catch limits and conducting stock assessments for bottomfish in Hawai'i, American Samoa, Guam, and the CNMI. With the exception of uku (*Aprion virescens*) in the main Hawaiian islands, all of these finfish groups are managed as a multi-species complex which can both limit and complicate our ability to directly or indirectly incorporate climate information into stock assessments. Climate impacts on stock assessment parameters are most often intuitively associated with 1) biomass index standardization, 2) individual growth and maturation, 3) natural mortality, and 4) recruitment.

Biomass index standardization is often the easiest way to incorporate climate sensitivity, and thus climate change, into stock assessments. Species whose distributions are sensitive to environmental conditions can lead to uneven catchability within fishing grounds over time. Incorporation of these associations with environmental conditions can improve our ability to disentangle changes in catch rates due to population's fluctuations from changes in catch rates due to variable overlap of habitat with fishing grounds/fishing gear (i.e., catchability; Wilberg et al., 2009; Thorson 2016; Cao et al., 2017). However, index standardization does not explicitly relate climate to life history parameters in assessments and changes in catch rates associated with environmental conditions may be a combination of effects on catchability and true life history dynamics (e.g., localized recruitment changes or changes in natural mortality).

Climate effects on growth (and related changes in maturation and morphology) are perhaps an essential, yet often difficult, way to measure the effects of climate on fished taxa. This requires monitoring changes in length-at-age distributions or individual growth over a range of ocean temperature, prey availability, and potentially also stock status regimes (e.g., density-dependent growth), typically requiring multi-decadal monitoring. The common 'space for time' paradigm, where looking at growth rate differences between regions with disparate environmental conditions is done to account for how climate change may impact growth, has a number of pitfalls, such as confounding environmental covariates and stock-specific dynamics (Lovell et al., 2023). Thus, long-term sampling of growth rates in a given region is ideal, though rare and data-intensive.

Natural mortality and recruitment can also have substantial effects in variation in biomass yet can be difficult to accurately quantify generally, let alone in terms of climate sensitivity. Climate/time varying natural mortality has been considered for stock assessments before, including for Atlantic cod and New Zealand red rock lobster (Pershing et al., 2015, Chen et al. 2022, Roberts et al., 2025), though rarely actually incorporated. It may also have profound effects on stock size, at extremes leading to rapid mortality that can result in fishery closures as in the case of snow crab in the Bering Sea (Litzow et al., 2024). Despite the clear influence of natural mortality on fish population size and dynamics and the potential urgency of improving our knowledge on how climate change may influence this process, we know very little about natural mortality rates of most fished marine species. These parameters are often "guesses" in models based on limited information.

Recruitment is also expected, and has been observed to be, highly sensitive to environmental changes. Recruitment processes can be immensely influential in population dynamics, with changes in recruitment strength driving pronounced fluctuations in the stock biomass of species ranging from anchovies to tunas (Kolody et al., 2019; Han et al., 2023). Recruitment, however, is another parameter that is rarely measured directly in fisheries stocks. Model estimated recruitment deviations (i.e., residuals from a pre-subscribed stock-recruitment curve) are often

statistical artifacts within stock assessments used to account for fluctuations in catch rate or catch size composition that are not easily subscribed to varying fishing mortality, growth, or distribution. These deviations may be true representations of recruitment, though can also be highly responsive to assumptions of historical catch, changes in catchability, the representativeness of catch rate/catch sampling data, and other processes/assumptions. Hence, it is often cautioned not to treat the model estimates as an accurate representation of true recruitment (Brooks and Deroba, 2015). Even so, some previous assessments have had success with including an SST covariate of recruitment (e.g., North Sea cod, New Zealand red rock lobster) (Nicolas et al. 2014, Rudd et al. 2023) with improvements for predicting future productivity.

Among these ways to account for climate variability and change in the U.S. Pacific Islands fisheries stock assessments, biomass index standardization remains the most achievable mechanism, given the available data. Indeed, environmental drivers of catchability have been previously considered in the main Hawaiian islands Deep-7 bottomfish stock assessment (Syslo et al., 2021) and have been explored for swordfish within the Hawai'i shallow-set longline fishery (Sculley & Brodziak 2020; Suca et al., in prep). 'Habitat-based' models have also been developed to improve estimates of the relative abundance of Pacific bigeye tuna (Bigelow et al., 2002), while oceanographic features have been considered within the WCPO-wide standardisation of pole and line CPUE for skipjack tuna through the application of a SST 'mask' to act as a spatial filter that excluded data from cells considered to have environmentally unsuitable habitats (Nishimoto et al., 2025) Further, studies generating catch rate and interaction probability models for target and secondary target species (Suca et al., in prep) and protected species (Siders et al., 2020, Van Wert et al., 2025; Mukai et al., in prep) driven by environmental covariates allow us to move toward understanding how climate oscillations and change will impact catchability of these taxa around Hawai'i. These efforts can both help stakeholders prepare for species movements and managers for changes in protected species interactions. This is particularly important in Pacific Island regions with large Marine Protected Areas (MPAs) that can lead distribution shifts to change accessibility of species to fishing if they move across MPA boundaries. While these are a step in the right direction, index standardization does not truly move us toward understanding population dynamics.

Much less has been done on climate impacts on growth, natural mortality, and recruitment of federally managed species in the region. Temperature-dependent growth has been observed for some species, such as bluespine unicornfish (*Naso unicornis*) in the Marianas archipelago (Reed et al., 2025), though this has not fed directly to assessments at this point. Further, research has shown environmental sensitivity of recruitment deviations for uku in the main Hawaiian islands (Suca et al., 2025), though this connection is to wind dynamics which are presently not easily or consistently forecasted around Hawai'i in climate change scenarios. Additional directed studies to learn more about life history sensitivity to climate change for federally managed species could

prove helpful in making the next step toward climate-informed stock assessments. We caution against indirect methods, such as looking into recent trends in recruitment deviations, owing to 1) uncertainty in the degree to which life history parameters, natural mortality, and recruitment deviations in our stock assessments reflect reality, 2) the multi-species complex assessments for bottomfish that can either obscure or simply not utilize individual species-level life history parameters, and 3) the lack of clear climate change signals in some regions–especially Hawai'i where we have our only single-species assessments in the U.S. Pacific Islands. Owing to these limitations, we are currently best prepared to provide information on catchability for pelagic species that are primarily managed by international bodies. Life history information such as growth and reproductive information (e.g., spawning timing, age at maturity, larval occurrences) and distribution information (catch patterns) can be informative for international-scale models such as SEAPODYM (e.g., Lehodey et al., 2008), and thus contribute to international management–even if we are presently not well suited to answer similar questions for our bottomfishes.

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