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Putting Regional Fisheries Management Organisations' Climate Change House in Order

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ABSTRACT

Climate change is expected to have significant impacts on the biology, abundance and distribution of transboundary fish stocks, not only among neighbouring countries within the jurisdictions of regional fisheries management organisations (RFMOs) but also between adjacent RFMOs. Using South Pacific albacore tuna (*Thunnus alalunga*) as a case study, we highlight how RFMOs need to understand the impacts of climate change on transboundary stocks under their purview with greater certainty. We identify four areas of research that should assist RFMOs to adapt their scientific processes—strengthened understanding of changes in the biology of target stocks; enhanced collection of data to support modelling; improved modelling of catch-per-unit of effort (CPUE) to better reflect climate change impacts on stock abundance for assessments; and ensuring that scientific advice is adaptive and robust to climate change, including through implementation of tested harvest strategies. Investments in these research areas should enable RFMOs to improve the science underpinning management measures designed to sustain transboundary stocks and increase fishery performance during climate change.

1 | Introduction

Fisheries based on transboundary stocks provide a substantial portion of the world's fish supply (FAO 2024). For many developing countries, particularly small island developing states, these fisheries also provide one of the few opportunities to support livelihoods and fund basic public services (Gillett and Fong 2023).

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Etymology of Ghoti: George Bernard Shaw (1856–1950), polymath, playwright, Nobel prize winner, and the most prolific letter writer in history, was an advocate of English spelling reform. He was reportedly fond of pointing out its absurdities by proving that 'fish' could be spelt 'ghoti'. That is: 'gh' as in 'rough', 'o' as in 'women' and 'ti' as in palatial.

Regional fisheries management organisations (RFMOs) with responsibility for managing highly migratory species, such as tuna, have had mixed success in ensuring that stocks under their management are not overfished and that overfishing is not occurring (ISSF 2023).

Climate change poses an additional challenge for RFMOs—it is expected to have a significant impact on marine ecosystems and the biology, abundance and distribution of fish stocks (Barange et al. 2018; Blanchard and Novaglia 2024). In the case of transboundary fisheries for highly migratory stocks, there is much potential for the effects of climate change to create 'winners' and 'losers' as fish biomass is redistributed across maritime boundaries (Pinsky et al. 2018; Oremus et al. 2020; Bell et al. 2021; Palacios-Abrantes et al. 2025). We argue that RFMOs need to 'put their house in order' by ensuring that the long-standing scientific processes they use to inform sustainable management of transboundary stocks are robust to climate change and related uncertainties.

Here, we focus on the scientific information needed to inform improved cooperative management between RFMOs identified during a workshop convened by the University of Wollongong, Shanghai Ocean University and the Pacific Community (SPC), using the anticipated effects of climate change on South Pacific albacore tuna (*Thunnus alalunga*) (hereafter 'SPA') as a case study.

South Pacific albacore provides a useful example of the need for further targeted research because: (i) it spans the convention areas of the Western and Central Pacific Fisheries Commission (WCPFC) and Inter-American Tropical Tuna Commission (IATTC); (ii) the spatial stock structure of SPA across the combined jurisdictions of these RFMOs is still not well defined (Moore et al. 2020); (iii) a notable proportion of the catch from both convention areas is taken from the high seas; (iv) fishing effort needs to be reduced to improve the economic performance of the fishery (Pilling et al. 2016); and (v) climate change is projected to have impacts on the abundance and distribution of the species (Lehodey et al. 2025) (Figure 1).

The recommended areas of research identified during the workshop are expected to be relevant not only to adjacent RFMOs but also to neighbouring countries within an RFMO convention area.

2 | Recommended Areas of Research

The four areas of research that will provide RFMOs with more robust climate-informed scientific advice identified during the workshop are summarised below.

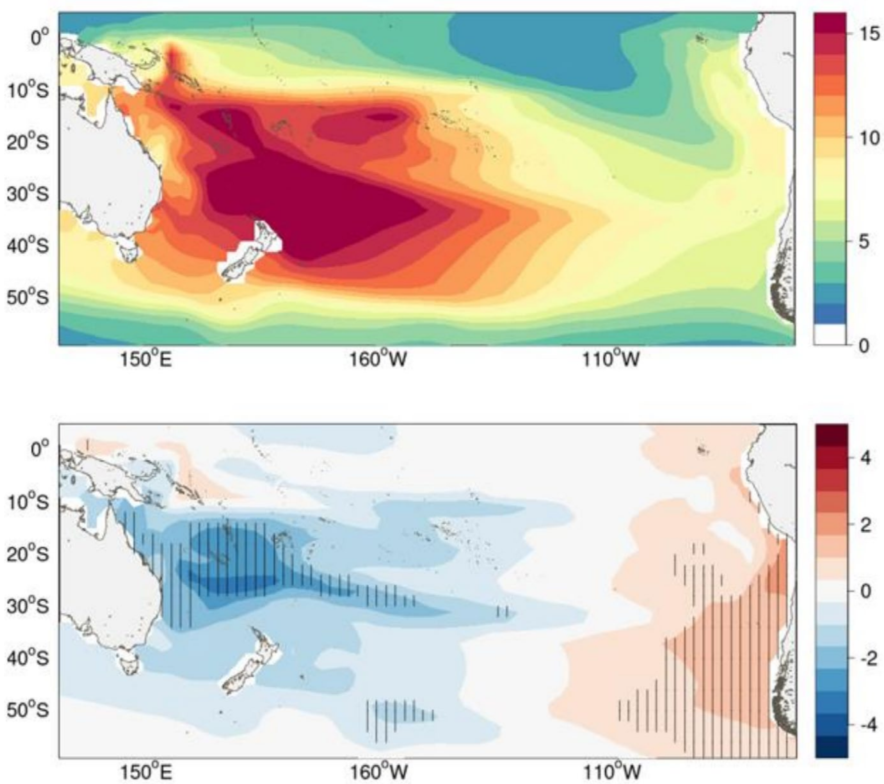

FIGURE 1 | Projected effects of climate change on the distribution of South Pacific albacore tuna (SPA). Average biomass distribution (kg.km^{-2}) of SPA in the Southern Pacific Ocean basin for 2015 (2011–2020) (top), and mean anomalies (kg.km^{-2}) from the average 2015 biomass distribution projected to occur by 2050 (2044–2053) under the RCP 8.5 emissions scenario (bottom). Shading indicates areas where projections from all four Earth Systems Models used to inform SEAPODYM agree in the sign of change, excluding near-zero changes (white zones). See Bell et al. (2021) and Senina, Lehodey, Sibert, and Hampton (2020) for a full description of the same methods applied to other tropical tuna species.

2.1 | Strengthen Understanding of Changes in the Biology of Target Stocks

A sound understanding of spatial stock structure, growth, fecundity and natural mortality is central to developing high-quality stock assessments to underpin the harvest strategies increasingly used by RFMOs to manage transboundary stocks. The current generation of population dynamics models typically assumes that these biological factors do not vary over time (Zhang et al. 2021). This is unlikely to hold during climate change, given the sensitivity of fish biology to the direct and indirect effects of ocean warming (Wootton et al. 2021; Nicol et al. 2022; Lehodey et al. 2025). To ensure that stock assessments remain fit for purpose, responses to projected changes in environmental conditions for key aspects of target species' life histories and ecological interactions need to be integrated into research frameworks.

Recent studies on North Pacific albacore tuna confirm the need for this approach—they indicate that changes in the marine environment and ecosystems may have unique impacts on different size-age classes due to their distinct habitat preferences, physiological tolerances, ecological niches and patterns of vertical and horizontal movement (Muhling et al. 2022; Frawley et al. 2024).

Other aspects of the biology of SPA also indicate that there is considerable scope for their life history to be altered by ocean warming. Tagging data show that individuals undertake long-range migrations across the South Pacific region and that smaller individuals in southerly latitudes move north to subtropical and tropical waters as they grow (Williams et al. 2015). In addition, analyses of genetic markers (Anderson et al. 2019), otolith chemistry (Macdonald et al. 2013), growth variability (Williams et al. 2012; Farley et al. 2021), gonad development (Farley et al. 2013) and maturity schedules (Farley et al. 2014), as well as the latest stock assessment (Teears, Castillo-Jordán, et al. 2024) and SEAPODYM analyses (Senina, Lehodey, Hampton, and Sibert 2020), reveal variation in life history across the longitudinal range of SPA. This variation indicates that the panmictic stock structure across the WCPO and Eastern Pacific Ocean (EPO) applied in the 2024 SPA stock assessment warrants further analysis. Variation in otolith shape and genetic data between individuals caught in New Caledonia and French Polynesia (Macdonald et al. 2024) also lends weight to the need for further analysis of potential spatial structure in the SPA stock.

The studies summarised above point to the need to assess whether (i) separate management measures may be required for SPA in the WCPO and EPO, and (ii) the extent to which ecosystems in the WCPO and EPO are projected to change under continued high greenhouse gas (GHG) emissions (Bell et al. 2021).

Application of new and emerging techniques, such as Close-Kin Mark-Recapture (CKMR) (Bravington et al. 2021; Macdonald et al. 2024; SPC-OFP and CSIRO 2024), to SPA are expected to provide new estimates of connectivity across the South Pacific and other difficult-to-measure population variables, such as absolute abundance, adult mortality and fecundity at age (Bravington et al. 2016). Long-term application of these techniques offers a novel way to detect population change not only for SPA but also for other transboundary target species in RFMOs.

2.2 | Enhance Collection of Data to Support Modelling

Ignoring variation in the fundamental biological factors described above may have implications for stock assessment performance and related management advice. Implementing appropriate long-term data collection programmes is therefore needed to detect when shifts in the mean and variability of values of fundamental biological factors occur.

In addition, improved understanding of the oceanographic, biological and human responses to climate change and their implications for fisheries management depends on developing spatially explicit models that can inform authorities about the impacts of climate change on fishing operations. It also depends on reducing uncertainty in the relationships between environmental variables, fleet dynamics and stock status/productivity that underpin the predictive models designed to test the performance of management actions in a changing environment.

Greater use of both fishery-dependent and fishery-independent data is required to meet this challenge. Both types of information are needed to increase the breadth and resolution of the biological, ecological and oceanographic data traditionally relied upon for stock assessment and resource allocation. The reason for this is that fishery-dependent data typically reflect commercial fishing activities and may not fully capture the true status and dynamics of fish populations in response to climate change; whereas fishery-independent data collection can be designed to address specific questions.

However, collecting fishery-independent data for transboundary stocks such as tuna is not without its difficulties. These include the extensive movements and evasive behaviour of the fish, their occurrence in deep pelagic zones (Kolody et al. 2019), and the advanced equipment, high operational costs and international coordination required for effective sampling programs across the broad geographical distributions of the species. A practical way to overcome these challenges is to maximise opportunities to collaborate with fishing fleets to obtain data not currently available from fishing operations.

SPC is undertaking trials using water temperature sensors fitted to longline gear deployed by vessels targeting SPA. Applications of this technology in New Zealand's exclusive economic zone have resulted in a 40% improvement in estimates of thermocline depth and ocean heat content (Kerry et al. 2024). Initiatives are also underway to collect environmental data from standard equipment commonly used by most fishing vessels (e.g., acoustic systems) to produce high-resolution spatial and temporal information on tuna prey populations from these 'ships of opportunity'.

Detecting shifts in the life history of target species requires ongoing collection of biological samples across the species' range. Diversifying the roles of at-sea and port-based observers to regularise biological sampling (Nicol et al. 2013) for target fish species in the Pacific Ocean has established a network to provide training in coordinated and extensive biological sampling of large numbers of SPA in particular (SPC-OFP and CSIRO 2024). The network helps ensure that the quantity and quality of samples required for CKMR can be obtained; it demonstrates the important role that RFMOs and other regional organisations can play in achieving improvements in large-scale sampling.

The need for additional fishery-dependent data, including more age samples to better characterise the distribution of age-at-length of the catch across different fishery regions, was recognised during the 2024 SPA stock assessment (Teears, Castillo-Jordán, et al. 2024). This assessment was based on information from measurements of size composition, catch and catch-per-unit effort analyses for different fleets/gears (Potts et al. 2024; Teears, Hampton, et al. 2024), including one fleet, the New Zealand troll fishery, that catches predominantly juveniles (Neubauer and Hill-Moana 2024).

To reduce the costs involved in coordinating the collection of the additional data needed for improved modelling, RFMOs could encourage member countries to (i) enhance their capacity to conduct coordinated scientific surveys and research by implementing various incentives for the provision of fisheries-dependent data, including increased at-sea observer coverage through human or electronic monitoring; and (ii) provide a supporting framework for the use of fishing vessels and ships of opportunity as environmental data collection platforms.

2.3 | Improve Incorporation of Catch-Per-Unit of Effort (CPUE) to Better Reflect Climate Change in Stock Assessments

Standardised catch-per-unit effort (CPUE) data provide a key indicator of the relative abundance of a fish stock and are a key input to stock assessment models. However, given climate change's impact on fish abundance, distribution, migration patterns and biology, the implications for fleet dynamics and fishing success through time will need to be better understood and captured within the standardisation process to ensure that those CPUE indices provide an unbiased reflection of the trend in stock abundance.

Incorporating new information will require the evaluation of new modelling techniques for the development of abundance indices. Traditionally, CPUE analyses relied heavily on generalised linear models (GLMs) and similar statistical methods (Hinton and Maunder 2004). However, recent advancements in modelling techniques have significantly enhanced fisheries stock assessments. Generalised additive models (GAMs) and their extensions to generalised additive mixed-effects models (GAMMs) enable sophisticated spatial and temporal modelling of nonlinear relationships, effectively accounting for complex fishing operational, ecological and environmental influences on catch rates (Augustin et al. 2013).

Machine learning techniques, including tree-based methods, have enhanced predictive capabilities. For example, a random forest (RF) machine learning approach was used to predict missing hook-based fishing effort records, demonstrating the algorithm's computational efficiency and its ability to handle large datasets (Breiman 2001; Teears et al. 2023). These methods enable exploration of interactions among different operational variables, further improving CPUE standardisation (Maunder et al. 2020).

Spatiotemporal modelling approaches can yield more precise, biologically reasonable, and interpretable estimates of fish abundance compared to design-based or spatially stratified models (Shelton et al. 2014; Grüss et al. 2019). Incorporating spatiotemporal random effects can serve as proxies for dynamic environmental variables, particularly when interactions between these effects are included to account for temporal variations in unmeasured environmental conditions at any given spatial location (Hoyle et al. 2024) and characterise distribution shifts, thereby enhancing the robustness and reliability of estimates.

Another significant development in modelling is the use of geostatistical models based on Gaussian Random Fields (GRFs), which reduce estimation errors compared to traditional methods that model spatial patterns as stratified regions (Zhou et al. 2019). This approach, using sdmTMB[1] (Anderson et al. 2024), has been used in CPUE analyses for recent WCPO tuna assessments, including for SPA (Teears, Castillo-Jordán, et al. 2024). This geostatistical approach, incorporating advanced techniques, such as Integrated Nested Laplace Approximations (INLA), allowed for the inclusion of additional covariates and improved the representativeness and explanatory power of the CPUE models (Magnusson et al. 2023; Teears et al. 2023).

Within WCPFC's 2024 SPA stock assessment, the impact of habitat suitability on CPUE was incorporated pragmatically by excluding data from spatial cells where the mean surface temperature over the period was $<16^{\circ}$C (Teears, Hampton, et al. 2024). With improved understanding of the impact of climate change in the Pacific, these approaches can be refined in future models. The application of this very simplistic temperature threshold could be improved by building in habitat suitability variables from models such as SEAPODYM (Senina, Lehodey, Hampton, and Sibert 2020; Senina, Lehodey, Sibert, and Hampton 2020) as covariates in the spatiotemporal CPUE models.

Most current treatments of CPUE data and their environmental influences focus on the two-dimensional horizontal space. However, SPA and other tuna inhabit a three-dimensional ecosystem, with the vertical dimension being subject to considerable environmental variation on multiple time scales, including those relevant to climate change. Time series of longline CPUE data often form the basis of the abundance indices used within tuna assessments. The vulnerability, and hence fishing mortality, of SPA and other tuna to longline gear is strongly impacted by the depth distribution of the fish in relation to the depth of the fishing hooks. Both distributions are impacted by environmental characteristics that vary in time and space. For example, SPA depth distribution is strongly influenced by ambient temperature, the level of dissolved oxygen and prey availability; and the fishing depth of longline hooks is determined both by the physical characteristics of the gear (hooks between floats, branch line length) and local environmental conditions, particularly currents. These variables will be influenced by climate change.

Early attempts to employ 'habitat-based' CPUE models (e.g., Bigelow et al. 2002) usefully demonstrated the importance of environmental variability on the interpretation of longline CPUE, but data on the depth distribution of the tuna were lacking. In recent years, more data on the environmental drivers of tuna depth distribution have become available through archival tagging studies (Fuller et al. 2015; Williams et al. 2015; Abascal et al. 2018). The use of these data to characterise tuna depth distribution in time and space has the potential to inform inclusion of other physicochemical variables as covariates in CPUE analysis to improve the reliability of CPUE-based indices of relative abundance of SPA.

RFMOs need to ensure CPUE standardisation models continue to develop in ways consistent with global best practice, and a collaborative approach is recommended. These models need to be cognisant of the potential impacts of climate change to ensure that CPUE trends are representative of true abundance trends, rather than climate/oceanographic influences on spatiotemporal dynamics. To inform these models, time series of fine-scale data on fishery operations are needed, integrating vessel-level catch and operational data sources (i.e., logbooks, VMS records, electronic monitoring and observer reports, transshipment logs) with oceanographic variables (Frawley et al. 2022).

2.4 | Ensure Advice Is Adaptive and Robust to Climate Change, Including Through Harvest Strategies

Scientific advice and the associated management decision-making process at national and regional scales have often taken many years to develop. Adapting fisheries management to the impacts of climate change can also be expected to take time, progressing from alterations to the benchmarks or reference points used to assess stock status, through to the frequency and mechanisms with which advice is amended and delivered, and the way new fisheries regulations are implemented.

WCPFC has adopted depletion-based sustainability benchmarks for assessing tuna stock status, including for SPA (Teears, Castillo-Jordán, et al. 2024; Berger et al. 2013). These benchmarks use the estimated adult biomass as a proportion of that expected in the absence of fishing. Importantly, the depletion is estimated dynamically, which takes into account temporal changes in recruitment. Dynamic depletion metrics are considered to be more robust to uncertainties in our knowledge of tuna productivity parameters—in particular, the form and steepness of the stock–recruitment relationship—than the estimate of maximum sustainable yield used by many other RFMOs (Preece et al. 2011). Although the robustness of dynamic depletion metrics to the impacts of climate change is yet to be tested, they may be more robust where ocean warming affects the recruitment dynamics of a stock.

Benchmarks are applied within the harvest strategy being implemented to manage a fishery, and the effectiveness of that strategy needs to be tested in the face of climate change uncertainty. However, there is a subtle difference between adaptive and robust harvest strategies. Adaptive strategies emphasise the importance of using dynamic management measures that change over time through continuous learning about biological and ecological variations induced by ocean warming. Although adaptive strategies may be optimal, they are subject to higher risks, especially when the effects of increased GHG emissions are highly uncertain. They are also typically not based on preagreed tested rules (i.e., harvest control rules) for adjusting fishing opportunities. Robust harvest strategies are better able to cope with greater uncertainty while still achieving management objectives reasonably successfully (Charles 1998). However, their performance must still be monitored to enable their modification if significant change within the system leads to conditions in which the harvest strategy is no longer suitably robust.

The design of a management strategy will therefore be influenced by the extent to which the effects of climate change on ecosystems and fish populations are understood and built into a testing phase using computer simulations. The redistribution of SPA provides an example. Higher certainty that ocean warming will lead to the redistribution of SPA would enable WCPFC and IATTC to consider implementing management strategies that explicitly account for the expected spatial variation in biomass. Conversely, if the effects of ocean warming on recruitment and productivity of SPA are quite uncertain, management strategies can be developed that are robust to those uncertain climate-induced changes in productivity and their performance monitored.

Management strategy evaluation (MSE) is a useful way to test different types of strategies and scenarios at various levels of uncertainty, simulated via different sets of operating models. For example, uncertainties against which candidate WCPFC harvest strategies for SPA are to be tested include elements of the impact of future climate change (Scott et al. 2024).

We recommend that RFMOs use simulation analyses such as MSE to test proposed management strategies against desired benchmarks (objectives) and develop strategies that account for climate change uncertainty. Ensuring the climate robustness of the existing or proposed management framework in the near term will allow RFMOs to adapt their wider processes to ensure decision-makers are confident that they are receiving the best scientific advice.

3 | Conclusion

There is a pressing need for RFMOs to collaboratively embrace the scientific advice required to co-ordinate sustainable harvests for transboundary stocks between and within their jurisdictions as climate change alters the distribution and abundance of fish. Investments in the four areas of research identified through the SPA case study not only promise to inform improved frameworks for cooperative management between WCPFC and IATTC called for by Goodman et al. (2022); they should also provide examples for other RFMOs to sustain the production of other stocks impacted by climate change. To fulfil their important roles effectively in the face of climate change, RFMOs will need to ensure that the advice they receive on the impacts of ocean warming on the biology of target species, and the incorporation of this knowledge within the modelling processes they depend on to inform harvest strategies, is relevant, timely and robust.

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Conflicts of Interest

The authors declare no conflicts of interest.

Data Availability Statement

Data sharing not applicable to this article as no datasets were generated or analysed during the current study.

Endnotes

[1] Species distribution model (sdm) Template Model Builder (TMB) is an R package described in Anderson et al. (2024).

References

Abascal, F. J., T. Peatman, B. Leroy, et al. 2018. "Spatiotemporal Variability in Bigeye Vertical Distribution in the Pacific Ocean." *Fisheries Research* 204: 371–379. https://doi.org/10.1016/j.fishres.2018.03.013.

Anderson, G., J. Hampton, N. Smith, and C. Rico. 2019. "Indications of Strong Adaptive Population Genetic Structure in Albacore Tuna (*Thunnus alalunga*) in the Southwest and Central Pacific Ocean." *Ecology and Evolution* 9, no. 18: 10354–10364. https://doi.org/10.1002/ece3.5554.

Anderson, S. C., E. J. Ward, P. A. English, L. A. K. Barnett, and J. T. Thorson. 2024. "sdmTMB: An R Package for Fast, Flexible, and User-Friendly Generalized Linear Mixed Effects Models With Spatial and Spatiotemporal Random Fields." *bioRxiv*. https://doi.org/10.1101/2022.03.24.485545.

Augustin, N. H., V. M. Trenkel, S. N. Wood, and P. Lorance. 2013. "Space-Time Modelling of Blue Ling for Fisheries Stock Management." *Environmetrics* 24: 109–119. https://doi.org/10.1002/env.2196.

Barange, M., T. Bahri, M. C. M. Beveridge, K. L. Cochrane, S. Funge-Smith, and F. Poulain. 2018. *Impacts of Climate Change on Fisheries and Aquaculture: Synthesis of Current Knowledge, Adaptation and Mitigation Options*, 627. FAO Fisheries and Aquaculture Technical Paper. https://fao.org/policy-support/tools-and-publications/resources-details/en/c/1152846/.

Bell, J. D., I. Senina, T. Adams, et al. 2021. "Pathways to Sustaining Tuna-Dependent Pacific Island Economies During Climate Change." *Nature Sustainability* 4: 900–910. https://doi.org/10.1038/s41893-021-00745-z.

Berger, A., G. Pilling, C. Kirchner, and S. Harley. 2013. "Determination of Appropriate Time-Windows for Calculation of Depletion-Based Limit Reference Points." Ninth Scientific Committee 6–14 WCPFC-SC9-2013/MI-WP-02. https://meetings.wcpfc.int/node/8137.

Bigelow, K. A., J. Hampton, and N. Miyabe. 2002. "Application of a Habitat-Based Model to Estimate Effective Longline Fishing Effort and Relative Abundance of Pacific Bigeye Tuna (*Thunnus obesus*)." *Fisheries Oceanography* 11: 143–155. https://doi.org/10.1046/j.1365-2419.2002.00196.x.

Blanchard, J. L., and C. Novaglia. 2024. "Climate Change Risks to Marine Ecosystems and Fisheries." FAO Fisheries and Aquaculture Technical Paper 707. https://fao.org/family-farming/detail/en/c/1698073/.

Bravington, M. V., P. M. Grewe, and C. R. Davies. 2016. "Absolute Abundance of Southern Bluefin Tuna Estimated by Close-Kin Mark-Recapture." *Nature Communications* 7: 13162. https://doi.org/10.1038/ncomms13162.

Bravington, M. V., S. Nicol, G. Anderson, et al. 2021. "South Pacific Albacore Close-Kin Mark-Recapture: Update on Design. 17th Scientific Committee, Western and Central Pacific Commission, SC17-SA-IP-14." https://meetings.wcpfc.int/node/12572.

Breiman, L. 2001. "Random Forests." *Machine Learning* 45: 5–32. https://doi.org/10.1023/a:1010933404324.

Charles, A. T. 1998. "Living With Uncertainty in Fisheries: Analytical Methods, Management Priorities and the Canadian Groundfishery Experience." *Fisheries Research* 37: 37–50. https://doi.org/10.1016/S0165-7836(98)00125-8.

FAO. 2024. *The State of the World's Fisheries and Aquaculture 2024: Blue Transformations in Action*. Food and Agriculture Organisation of the United Nations. https://doi.org/10.4060/cd0683en.

Farley, J., K. Krusic-Golub, and P. Eveson. 2021. "Updating Age and Growth Parameters for South Pacific Albacore (Project 106)." 17th Scientific Committee, Western and Central Pacific Fisheries Commission, SC17-SA-IP-10. https://meetings.wcpfc.int/node/12568.

Farley, J. H., S. D. Hoyle, J. P. Eveson, A. J. Williams, C. R. Davies, and S. J. Nicol. 2014. "Maturity Ogives for South Pacific Albacore Tuna (*Thunnus alalunga*) That Account for Spatial and Seasonal Variation in the Distributions of Mature and Immature Fish." *PLoS One* 9, no. 1: e83017. https://doi.org/10.1371/journal.pone.0083017.

Farley, J. H., A. J. Williams, N. P. Clear, C. R. Davies, and S. J. Nicol. 2013. "Reproductive Dynamics and Potential Annual Fecundity of South Pacific Albacore Tuna (*Thunnus alalunga*)." *PLoS One* 8, no. 4: e60577. https://doi.org/10.1371/journal.pone.0060577.

Frawley, T. H., B. Muhling, S. Brodie, et al. 2024. "Dynamic Human, Oceanographic, and Ecological Factors Mediate Transboundary Fishery Overlap Across the Pacific High Seas." *Fish and Fisheries* 25: 60–81. https://doi.org/10.1111/faf.12791.

Frawley, T. H., B. Muhling, H. Welch, et al. 2022. "Clustering of Disaggregated Fisheries Data Reveals Functional Longline Fleets Across the Pacific." *One Earth* 5: 1002–1018. https://doi.org/10.1016/j.oneear.2022.08.006.

Fuller, D. W., K. M. Schaefer, J. Hampton, S. Caillot, B. M. Leroy, and D. G. Itano. 2015. "Vertical Movements, Behavior, and Habitat of Bigeye Tuna (*Thunnus obesus*) in the Equatorial Central Pacific Ocean." *Fisheries Research* 172: 57–70. https://doi.org/10.1016/j.fishres.2015.06.024.

Gillett, R., and M. Fong. 2023. *Fisheries in the Economies of Pacific Island Countries and Territories*. Pacific Community.

Goodman, C., R. Davis, K. Azmi, et al. 2022. "Enhancing Cooperative Responses by Regional Fisheries Management Organisations to Climate-Driven Redistribution of Tropical Pacific Tuna Stocks." *Frontiers in Marine Science* 9: 1046018. https://doi.org/10.3389/fmars.2022.1046018.

Grüss, A., J. F. Walter III, E. A. Babcock, et al. 2019. "Evaluation of the Impacts of Different Treatments of Spatio-Temporal Variation in Catch-Per-Unit-Effort Standardization Models." *Fisheries Research* 213: 75–93. https://doi.org/10.1016/j.fishres.2019.01.008.

Hinton, M. G., and M. N. Maunder. 2004. "Methods for Standardizing CPUE and How to Select Among Them." *Collective Volume of Scientific Papers ICCAT* 56: 169–177. https://iccat.int/Documents/CVSP/CV056_2004/n_1/CV056010169.pdf.

Hoyle, S. D., R. A. Campbell, N. D. Ducharme-Barth, et al. 2024. "Catch Per Unit Effort Modelling for Stock Assessment: A Summary of Good Practices." *Fisheries Research* 269: 106860. https://doi.org/10.1016/j.fishres.2023.106860.

ISSF. 2023. *Status of the World's Fisheries for Tuna ISSF 2023–12*. International Sustainable Seafood Foundation. https://www.iss-foundation.org/research-advocacy-recommendations/our-scientific-program/scientific-reports/download-info/issf-2023-12-status-of-the-world-fisheries-for-tuna-november-2023/.

Kerry, C., M. Roughan, and J. M. de Azevedo Correia Souza. 2024. "Assessing the Impact of Subsurface Temperature Observations From Fishing Vessels on Temperature and Heat Content Estimates in Shelf Seas: A New Zealand Case Study Using Observing System Simulation Experiments." *Frontiers in Marine Science* 11: 1358193. https://doi.org/10.3389/fmars.2024.1358193.

Kolody, D. S., J. P. Eveson, A. L. Preece, C. R. Davies, and R. M. Hillary. 2019. "Recruitment in Tuna RFMO Stock Assessment and Management: A Review of Current Approaches and Challenges." *Fisheries Research* 217: 217–234. https://doi.org/10.1016/j.fishres.2018.11.031.

Lehodey, P., I. Senina, S. Nicol, et al. 2025. "Implications of Climate Change for Oceanic Fisheries in the Tropical Pacific Islands Region." In *Climate Change Implications for Fisheries and Aquaculture in the Pacific Islands Region*, edited by J. E. Johnson and C. C. C. Wabnitz. Pacific Community (SPC).

Macdonald, J., G. Anderson, K. Krusic-Golub, et al. 2024. "Spatial Structure and Regional Connectivity of South Pacific Albacore Tuna in the WCPO and EPO." 20th Scientific Committee, Western and Central Pacific Fisheries Committee, SC20-SA-IP-04. https://meetings.wcpfc.int/node/23127.

Macdonald, J. I., J. H. Farley, N. P. Clear, et al. 2013. "Insights Into Mixing and Movement of South Pacific Albacore *Thunnus alalunga* Derived From Trace Elements in Otoliths." *Fisheries Research* 148: 56–63. https://doi.org/10.1016/j.fishres.2013.08.004.

Magnusson, A., J. Day, T. Teears, et al. 2023. "Stock Assessment of Yellowfin Tuna in the Western and Central Pacific Ocean: 2023." 19th Scientific Committee, Western and Central Pacific Fisheries Commission, SC19-SA-WP-04. https://meetings.wcpfc.int/node/19352.

Maunder, M. N., J. T. Thorson, H. Xu, et al. 2020. "The Need for Spatio-Temporal Modeling to Determine Catch-Per-Unit Effort Based Indices of Abundance and Associated Composition Data for Inclusion in Stock Assessment Models." *Fisheries Research* 229: 10559. https://doi.org/10.1016/j.fishres.2020.105594.

Moore, B. R., J. D. Bell, K. Evans, et al. 2020. "Defining the Stock Structures of Key Commercial Tunas in the Pacific Ocean I: Current Knowledge and Main Uncertainties." *Fisheries Research* 230: 105525. https://doi.org/10.1016/j.fishres.2020.105525.

Muhling, B. A., S. Snyder, E. L. Hazen, et al. 2022. "Risk and Reward in Foraging Migrations of North Pacific Albacore Determined From Estimates of Energy Intake and Movement Costs." *Frontiers in Marine Science* 9: 730428. https://doi.org/10.3389/fmars.2022.730428.

Neubauer, P., and T. Hill-Moana. 2024. "Characterisation, CPUE and Length-Composition Analyses of the New Zealand Albacore Fishery." 20th Scientific Committee, Western and Central Pacific Fisheries Commission, SC20-SA-IP-18. https://meetings.wcpfc.int/node/22993.

Nicol, S., P. Lehodey, I. Senina, et al. 2022. "Ocean Futures for the World's Largest Yellowfin Tuna Population Under the Combined Effects of Ocean Warming and Acidification." *Frontiers in Marine Science* 9: 816772. https://doi.org/10.3389/fmars.2022.816772.

Nicol, S. J., V. Allain, G. M. Pilling, et al. 2013. "An Ocean Observation System for Monitoring the Effects of Climate Change on the Ecology and Sustainability of Pelagic Fisheries in the Pacific Ocean." *Climatic Change* 119: 131–145. https://doi.org/10.1007/s10584-012-0598-y.

Oremus, K. L., J. Bone, C. Costello, et al. 2020. "Governance Challenges for Tropical Nations Losing Fish Species due to Climate Change." *Nature Sustainability* 3: 277–280. https://doi.org/10.1038/s41893-020-0476-y.

Palacios-Abrantes, J., B. S. Santos, T. L. Frölicher, et al. 2025. "Climate Change Drives Shifts in Straddling Fish Stocks in the World's Ocean." *Science Advances* 11: eadq5976.

Pilling, G. M., A. M. Berger, C. Reid, S. J. Harley, and J. Hampton. 2016. "Candidate Biological and Economic Target Reference Points for the South Pacific Albacore Longline Fishery." *Fisheries Research* 174: 167–178. https://doi.org/10.1016/j.fishres.2015.09.018.

Pinsky, M. L., G. Reygondeau, R. Caddell, J. Palacios-Abrantes, J. Spijkers, and W. W. L. Cheung. 2018. "Preparing Ocean Governance for Species on the Move." *Science* 360, no. 6394: 1189–1191. https://doi.org/10.1126/science.aat2360.

Potts, J., C. Castilo-Jordan, J. Day, P. Hamer, and T. Teears. 2024. "Analysis of Longline Size Frequency Data for the 2024 Southwest Pacific Striped Marlin and South Pacific Albacore Assessments." 20th Scientific Committee of the Western and Central Pacific Fisheries Commission, SC20-SA-IP-03. https://meetings.wcpfc.int/node/23064.

Preece, A., R. Hillary, and C. Davies. 2011. "Identification of Candidate Limit Reference Points for the Key Target Species in the WCPFC." 7th Scientific Committee, Western and Central Pacific Fisheries Committee, SC7-MI-WP-03. https://meetings.wcpfc.int/node/7305.

Scott, R., F. Scott, N. Yao, P. Hamer, and G. Pilling. 2024. "Selecting and Conditioning Operating Models for South Pacific Albacore." 20th Scientific Committee, Western and Central Pacific Fisheries Commission, SC20-MI-WP-04. https://meetings.wcpfc.int/node/23136.

Senina, I., P. Lehodey, J. Sibert, and J. Hampton. 2020. "Integrating Tagging and Fisheries Data Into a Spatial Population Dynamics Model to Improve Its Predictive Skills." *Canadian Journal of Fisheries and Aquatic Sciences* 77, no. 3: 439–635. https://doi.org/10.1139/cjfas-2018-0470.

Senina, I. N., P. Lehodey, J. Hampton, and J. Sibert. 2020. "Quantitative Modeling of the Spatial Dynamics of South Pacific and Atlantic Albacore Tuna Populations." *Deep Sea Research Part II: Topical Studies in Oceanography* 175: 104667. https://doi.org/10.1016/j.dsr2.2019.104667.

Shelton, A. O., J. T. Thorson, E. J. Ward, and B. E. Feist. 2014. "Spatial Semiparametric Models Improve Estimates of Species Abundance and Distribution." *Canadian Journal of Fisheries and Aquatic Sciences* 71, no. 11: 1655–1666. https://doi.org/10.1139/cjfas-2013-0508.

SPC-OFP, and CSIRO. 2024. "Progress Towards a Close-Kin-Mark-Recapture Application to South Pacific Albacore (Project 100c)." 20th Scientific Committee, Western and Central Pacific Fisheries Commission, SC20-SA-WP-09. https://meetings.wcpfc.int/node/23123.

Teears, T., C. Castillo-Jordán, N. Davies, et al. 2024. "Stock Assessment of South Pacific Albacore: 2024–Rev.03." 20th Scientific Committee, Western and Central Pacific Fisheries Commission, SC20-SA-WP-02. https://meetings.wcpfc.int/node/23119.

Teears, T., J. Day, J. Hampton, et al. 2023. "CPUE Analysis and Data Inputs for the 2023 Bigeye and Yellowfin Tuna Assessments in the WCPO." 19th Scientific Committee, Western and Central Pacific Fisheries Commission, SC19-SA-WP-03. https://meetings.wcpfc.int/node/19351.

Teears, T., J. Hampton, T. Peatman, et al. 2024. "Background Analyses and Data Inputs for the 2024 South Pacific Albacore Tuna Stock Assessment." 20th Scientific Committee, Western and Central Pacific Fisheries Commission, SC20-SA-IP-05. https://meetings.wcpfc.int/node/23128.

Williams, A. J., V. Allain, S. J. Nicol, et al. 2015. "Vertical Behavior and Diet of Albacore Tuna (*Thunnus Alalunga*) Vary With Latitude in the South Pacific Ocean." *Deep Sea Research, Part II* 113: 154–169. https://doi.org/10.1016/j.dsr2.2014.03.010.

Williams, A. J., J. H. Farley, S. D. Hoyle, C. R. Davies, and S. J. Nicol. 2012. "Spatial and Sex-Specific Variation in Growth of Albacore Tuna (*Thunnus alalunga*) Across the South Pacific Ocean." *PLoS One* 7: e39318. https://doi.org/10.1371/journal.pone.0039318.

Wootton, H. F., A. Audzijonyte, and J. Morrongiello. 2021. "Multigenerational Exposure to Warming and Fishing Causes Recruitment Collapse, but Size Diversity and Periodic Cooling Can Aid Recovery." *Proceedings of the National Academy of Sciences of the United States of America* 118: e2100300118. https://doi.org/10.1073/pnas.2100300118.

Zhang, F., K. B. Reid, and T. D. Nudds. 2021. "The Longer the Better? Trade-Offs in Fisheries Stock Assessment in Dynamic Ecosystems." *Fish and Fisheries* 22: 789–797. https://doi.org/10.1111/faf.12550.

Zhou, S., R. A. Campbell, and S. D. Hoyle. 2019. "Catch Per Unit Effort Standardization Using Spatio-Temporal Models for Australia's Eastern Tuna and Billfish Fishery." *ICES Journal of Marine Science* 76, no. 6: 1489–1504. https://doi.org/10.1093/icesjms/fsz034.