Drivers of conflict and resilience in shifting transboundary fisheries

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1. Introduction

Conflict over access and rights to fisheries resources has affected fishers and fish-dependent communities for centuries (Spijkers et al. 2019, Charles 1992, Bailey 1996). Fisheries conflict – defined here as disputes between two or more parties over the ownership, management, or usage of marine living resources – has historically been caused by a diverse range of drivers such as overfishing, stock distribution and migration, political instability, illegal, unreported, and unregulated (IUU) fishing, and scarcity (Mazurek & Burroughs 2018, Pomeroy et al. 2007, Spijkers et al. 2019, Dahlet et al. 2021, Spijkers et al. 2021). Fisheries conflicts vary in intensity and scale, from verbal disputes to violent altercations and from local to international (Spijkers et al., 2018, Devlin et al. 2021). The latter can range from confined conflicts between two vessels, such as the 2019 collision of two American vessels vying for tuna fishing grounds near Kiribati (The Maritime Executive 2021), to geopolitical conflicts such as the British-French disputes over fishing rights in a post-Brexit world (Victor 2021, Phillipson & Symes 2018), or ongoing fishery incidents in the South China Sea (Zhang & Bateman 2017, Hendrix et al. 2022).

Climate change is increasingly recognized as a key factor in fomenting fisheries conflicts (Kelman 2020, Mendenhall et al. 2020, Spijkers et al. 2021). In brief, increased greenhouse gas emissions and their effects on the physical and chemical processes of the ocean are causing fish stocks to move into deeper waters, farther offshore, poleward, or along new regional temperature isotherms (Clarke et al. 2022, Reygondeau 2019, Barange et al. 2018, Poloczanska et al. 2016, Parmesan 2006, Maureaud et al. 2021). Past research has focused on generating projections of where and when future shifts are likely to occur, including identifying hotspots of climate-induced stock shifts, or regions where ocean conditions are rapidly changing and expected to significantly alter fish stock distribution and abundance in the near future (Pinsky et al. 2013, Hobday & Pecl 2014, Palacios-Abrantes et al. 2022, Lima 2022, Cheung et al. 2016, Cheung 2018, Sumaila et al. 2020). Further work has explored the current and future challenges that fisheries management and governance bodies will inevitably face as a result of species on the move (Miller et al. 2013, Hobday et al. 2015, Gaines et al. 2018, Pentz et al. 2018, Pinsky et al. 2018, Cisneros-Mata et al. 2019, Dubik et al., 2019, Oremus et al. 2020, Sumaila et al. 2020, Palacios-Abrantes et al. 2020, Engler 2020, Mendenhall et al. 2020, Sumby et al. 2021, Goodman et al. 2022).

Projections tend to agree that fish stock productivity and abundance will, on average, decline near the equator and increase at higher latitudes (Cheung et al. 2017), with the geographic distributions of the so-called "winners" and "losers" having potentially dire socioeconomic implications for fishing nations (Free et al. 2019). It is important to note that this uniform directionality is not always the case (Clarke et al. 2020), and high levels of localized uncertainty can complicate proactive fisheries management efforts. Furthermore, in some cases, climate may act only as a peripheral contributor to conflict formation, with non-climatic drivers such as overexploitation, food insecurity, prevalence of IUU fishing, territorial disputes, and weak governance being strong if not primary drivers of conflict risk (Devlin et al. 2021, Spijkers et al. 2021, Mach et al. 2019, Buhaug et al. 2014, IPCC 2022, Song 2015). Regardless of the direction of the stock shift, as commercially important fish stocks move across international boundaries in search of more suitable habitats, who is responsible for their management can become less clear, and the potential for unsustainable harvest and international conflict increases (Palacios-Abrantes et al. 2022, Palacios-Abrantes et al. 2020, Pinsky 2018, Oremus 2020, Mendenhall et al. 2020, Lennan 2021). Additionally, as the number of countries competing for (i.e., sharing) the same fish stock increases, the abundance of that stock tends to decrease (Liu & Molina 2021). As a result, collaboration and cooperation are recognized as vital components of internationally shared stock management (Grønbæk et al. 2020).

The challenges posed by climate change to global fisheries have been recognized and addressed by international bodies such as the Food and Agriculture Organization of the United Nations (Barange et al. 2018) and by Regional Fishery Management Organizations (RFMOs), although the limited scope and uptake of RFMO climate change strategies is a topic of concern (Pentz et al. 2018, Pentz & Klenk 2020, Bryndum-Buchholz 2021, Sumby et al. 2021)

Here, we use a system-focused approach to analyze four transboundary fisheries – Atlantic halibut on the Canadian Shelf, coastal tuna in the Horn of Africa, Pacific saury in the northwest Pacific, and tuna in the central western Pacific – to explore the potential conflict formation or avoidance pathways that may arise due to species on the move. Predictive modeling studies (e.g., Palacios-Abrantes et al. 2022) can be variable and thus not always useful for short-term tactical decisions; therefore, it is important to supplement stock shift projections with contextual socioeconomic information to diagnose the potential for conflict formation or avoidance as a result of fish stock redistribution. An analysis of real-world case studies provides a deeper understanding of the drivers that lead to the formation or avoidance of conflict in transboundary fisheries, including why some institutions fail to adapt, enabling these lessons to be applied elsewhere to determine the courses of action that can prevent or reduce conflict.

In 2018, Spijkers et al. identified four scientific gaps that must be addressed to understand fisheries conflicts. We address one of those gaps – that of "complex adaptive systems thinking… [which] has the potential to produce more realistic causal models of fishery conflict" (Spijkers et al. 2018) using a social-ecological framework and an actor-centered rational choice approach (Scharpf 1997), integrating game theory, negotiation theory, translation cost economics, international relations, political ecology, and democratic theory. This framework can be contextualized within a two-sided continuum, drawing in equal parts from the case study-focused post-modernist approach and from the more generalized theoretical approach to conflict (Bennett et al. 2001).

Archetypes of stock shifts

To categorically analyze cases of internationally shared stock shifts and conflict, we utilize archetypes of stock shift based on the Food and Agriculture Organization's (FAO) definitions. This categorization rests upon the treaty providing the foundation for the management of internationally-shared fishery resources – the 1982 UN Convention on the Law of the Sea (UN 1982), which came into force in 1994. Of crucial importance is this Convention's establishment of the 200 nautical mile Exclusive Economic Zone (EEZ) regime, which is now all but universal. Waters beyond the EEZs constitute the remaining high seas.

The 1982 UN Convention on the Law of the Sea was found, over the ensuing decade, to be inadequate with respect to the management of highly migratory and straddling stocks. This led to a further UN conference, the UN Conference on Straddling Fish Stocks and Highly Migratory Fish Stocks, which brought forth the 1995 UN Fish Stocks Agreement (UN 1995), designed to supplement and buttress the 1982 Convention on the Law of the Sea. The Agreement led to the establishment of the regime of Regional Fisheries Management Organizations, or RFMOs.

The FAO generic term for internationally shared fishery resources is *shared fish stocks*. Under this generic heading, the FAO distinguishes (FAO 1995; Munro, Van Houtte & Willmann 2004):

a. transboundary stocks – fish stocks distributed across two or more EEZs;
b. highly migratory stocks – tuna and bill fishes primarily – which, because of their highly migratory nature, are found both within the EEZ and the adjacent high seas;
c. straddling stocks – all other stocks, which are to be found both within the EEZ and the adjacent high seas;
d. and discrete high seas stocks – stocks found in the high seas only.

Categories a. and b., and a. and c., are not mutually exclusive. There are, for example, many stocks, which are both transboundary and straddling in nature.

Adapting the above FAO definitions, we adopt four archetypes of jurisdictional shifts (Fig. 1): a) novel stock shifts between EEZs; b) novel stock shifts between the high seas and an EEZ; c) existing stock shifts between the high seas and an EEZ; and d) existing stock shifts between EEZs. We use the term 'transboundary' to encompass stocks that span multiple EEZs (FAO category a.), or between EEZs and the high seas (FAO categories b. and c.) (Munro, Van Houtte & Willmann 2004). Novel stocks refer to species that are crossing a geopolitical boundary for the first time, while existing stocks were present on both sides of a boundary prior to the climate-driven shift but are now altered in distribution or abundance. An initial assumption that contributed to this categorization was that a combination of novel stock appearance/disappearance and resource transfer across international boundaries would create the highest risk of potential conflict. This assumption is explored further in the Discussion section. When considering shifts of fish stocks from an EEZ to adjacent high seas, a key consideration for conflict formation is whether the relevant fish stocks are governed under RFMOs, which oversee management and accounting of internationally shared stocks. The ways in which redistributed fisheries resources are assessed, allocated and managed can have negative repercussions for food security (Hobday et al. 2015, Wabnitz et al. 2018), equity (Oremus et al. 2020, Hanich et al. 2015), and the general wellbeing of fish-dependent nations around the world (Gaines et al. 2018), all of which are considered in the case studies and analyses that follow.

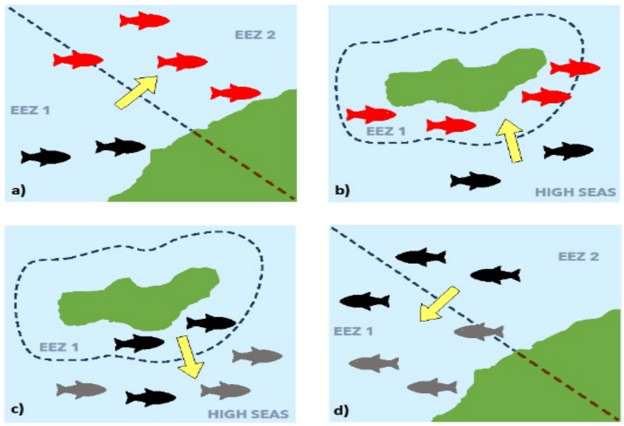

Figure 1 Graphic depiction of the four archetypes of stock shift used in this study, with: a) novel stock shifts between EEZs; b) novel stock shifts between the high seas and an EEZ; c) existing stock shifts between the high seas and an EEZ; and d) existing stock shifts between EEZs. In all cases, transboundary movement can occur in either direction (i.e., from the high seas into an EEZ, or vice versa). Black fish denote stocks that were already present in the region prior to shift. Red fish denote novel stocks shifting across jurisdictional boundaries into new areas. Gray fish are existing stocks that have shifted across boundaries to alter distributions between the two regions. Yellow arrows represent the general direction of shift across boundaries. Green represents land. Types a and d are associated with transboundary stocks (shared between EEZs) and types b and c could apply either to straddling stocks (shared between EEZs and the high seas) or highly-migratory stocks.

2. Methods

The findings presented here were produced over several stages of structured expert elicitation and working group collaboration. This approach was chosen for several reasons, including its focus on aggregating and identifying areas of agreement and disagreement across a diverse body of experts, its suitability for trans-disciplinary collaboration, and its focus on knowledge co-production (Bedford et al. 2006, Hemming et al. 2017). Through this approach, we do not adopt a particular framework or underlying theory, and instead draw on the expert knowledge of this limited group to highlight helpful insights that arise from this participatory and transdisciplinary approach. The field of international governance, cooperation and conflict resolution has been well developed since the Law of the Sea in 1995, and this paper focuses on the additional complexities caused by rapid climate change. The stages of this research process can be roughly separated into two methodological categories: **theoretical** and **empirical**.

The first stage of this project was **theoretical** in nature and consisted of a virtual two-day workshop convened by the Environmental Defense Fund in March 2022. This workshop brought together 25 multi- and trans-disciplinary experts to discuss links between shifting stocks and conflict, and to co-create a causal model of fisheries conflict. Workshop participants were selected based on relevant publications and past or current participation in projects related to the topics of shifting stocks and fisheries conflict. Selected experts came from a variety of disciplines, including marine ecology, political geography, fisheries economics, and conflict studies. At the time of the workshop, participants were working in academia, non-governmental organizations, and governmental organizations, and although none were directly employed by them, had deep experience with RFMOs and international governing bodies such as the United Nations.

During the first day of the workshop, participants formed a shared understanding of climate change-induced stock shifts and conflict by co-creating a General Causality Model (Fig. 2) of the potential drivers and types of conflict that can occur when stocks move across international boundaries. This exercise drew on prevalent theories such as strategic interaction (or game theory) to guide our understanding of the complexities of multilateral cooperation and the so-called threat points that might prompt conflict to arise (see Box 1). The second day of the workshop focused on identifying attributes of resilience to these potential conflicts and identifying hotspots where transboundary fisheries conflicts are likely to occur. The General Causality Model and the hotspot identification activities laid the groundwork for the findings presented here.

Box 1 - Game Theory & Fisheries Conflict (Sources: Clark & Munro 1975, Sumaila et al. 2020)

The **theory of strategic interaction**, more popularly known as game theory, is applicable to situations in which the actions of one "individual" have a perceptible impact upon one or more "individuals", leading to a strategic interaction between or among those "individuals". Central to the problem of managing internationally shared fishery resources is that, with few exceptions, there is a strategic interaction between/among those states sharing the resources. Thus, for example, consider a transboundary fishery resource shared by two coastal states, A and B. In other than exceptional circumstances, the harvesting activities of the A (B) fleet will have an impact upon the harvesting opportunities open to the B (A) fleet, and each fleet owner, aware of this fact, will consider this in its actions – hence the strategic interaction.

Game theory can be divided into two broad categories – the theory of non-cooperative games and that of cooperative games. The famous prediction of this theory is that, under non-cooperation, players will be driven to adopt courses of action (or strategies) which they know to be harmful, leading to conflict, or a "lose -lose" situation (Grønbaek et al. 2020). Cooperation does, with few exceptions, matter. The predictive power of the theory of non-cooperative games, with respect to the management of internationally-shared fishery resources, has proven over the decades to be very high indeed, leading policy makers (e.g., FAO 2002) to insist that international cooperation among those countries sharing fishery resources is a fundamental prerequisite for effective management of the resources.

The theory of cooperative games, which is much more complex, is designed to explore the conditions that must prevail for cooperation to be stable and enduring, and to explore means of satisfying the conditions. Cooperative games, which do not meet all of the conditions, will degenerate into non-cooperative games, with all that that implies. Some of the conditions are obvious, but in the real world of fisheries cooperative management agreements, the obvious is often ignored.

To begin, there is a basic assumption in the theory that the players/agents are motivated by self-interest alone, that they will not cooperate unless it is in their self-interest to do so. With this assumption in mind, the basic conditions to be met are first that the players/agents must at all times be able to communicate effectively with one another. The second condition, referred to in game theory jargon as the individual rationality condition, is that each and every player at each and every moment in time must anticipate a return (or "payoff") from cooperation at least as great as the "payoff" that it would anticipate receiving under non-cooperation.

The third condition, and by far the most difficult to satisfy, is a dynamic condition, which we can best be termed *resilience*. The cooperative game, in our case taking the form of a cooperative fisheries management agreement, must have the flexibility to withstand through time unpredictable shocks arising from environmental, economic, political or from other sources (Grønbaek et al. 2020). Unpredictable climate-induced shifts in marine species provide a key example that is explored further in this paper.

Following the workshop, a smaller working group of ten experts was selected based on relevance and interest from the larger workshop. This group met regularly to further explore the General Causality Model and to identify research gaps identified during the workshop, with a focus on the lack of comprehensive narrative case studies that explore the role of climate change-induced, transboundary stock shifts in the formation of conflict over fishery resources. To fill this gap, the group then developed a structured survey to collect information from regions of the world where transboundary stock shifts occur, and where potential for associated conflict exists.

At this stage the methodology transitioned from the theoretical to the **empirical**. The survey was distributed via an open access Google Form using the snowball sampling method (Naderifar, Goli &

Ghaljaie 2017) to reach a broader pool of regional experts who were identified via literature review and recommendations from workshop participants. The survey (see Supplementary Materials) was structured so that respondents were guided through the components of the general causality model developed in the workshop (Fig. 2). The survey questions and subsequent analyses are grouped into the following categories: contextual factors, stock governance, conflict, and resilience.

Ten experts responded to the survey (see Table 1). The scope of this outreach effort was limited by our ability to find and engage with experts across all relevant industries, such as RFMOs. This lack of diversity is a clear limitation of this study and should be addressed in further research on this topic. Despite this, the purpose of this survey was not to be representative of the entire array of possible conflicts, but instead, to demonstrate cases and practices in some parts of the world. The four case studies were selected based on completeness of survey responses, willingness of the respondent to engage further in the writing process, geographic diversity, and availability of sufficient information regarding the stock and conflict scenarios.

Table 1 - Background information on the ten survey respondents. The survey was distributed via email using the snowball method.

Respondent	**Affiliation**	**Region**
1	Non-governmental Organization	South America
2	Academic institution	Canada
3	Non-governmental Organization	United States
4	Academic institution	United States
5	Government	Canada
6	N/A	Europe
7	Government	Canada
8	Government	Canada
9	Non-governmental Organization	United States
10	Non-governmental Organization	Australia

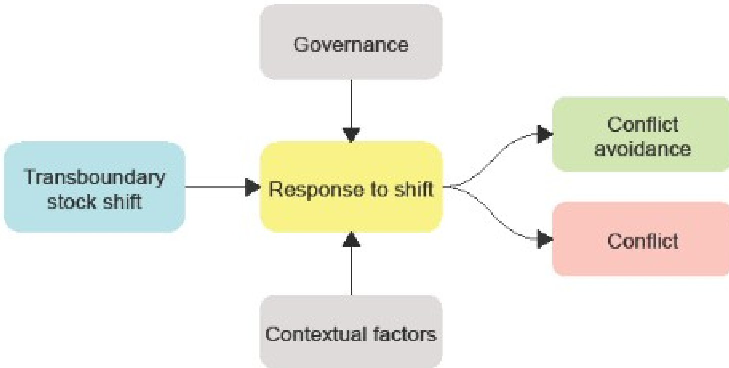

Figure 2 General Causality Model developed during the initial workshop in March 2022. This model was used to identify the attributes to be collected for each case study, and the components are mirrored in the case study analyses reported in Figure 4. This model was expanded after case study collection into the Synthesis Model (Figure 5).

Our four case studies examine stock losses/gains from one EEZ to another (archetype d), and from an EEZ to/from the adjacent high seas (archetype c). Our survey process was unable to produce examples of archetypes a and b – an omission which is explored further in the Discussion. Case study analyses were guided by the General Causality Model (Fig. 2), which assumes that redistribution and uncertainty regarding resource sharing due to climate change, combined with contextual factors and governance systems, may lead to either conflict or conflict avoidance depending on the nature of the response. After reviewing the case studies, context-specific causal models were made for each case (see Supplemental Materials), and a Synthesis Model (Fig. 5) was extrapolated from themes common across the four individual models.

3. Results

The four case studies are listed in Table 2 and visually depicted in Figure 3. Full narratives are included in Supplemental Materials. Table 2 displays contextual factors and vital background information for each case study. Figure 4 summarizes the cross-cutting findings observed across multiple cases, and the remainder of this section expands upon the four main categories of analysis – Contextual factors (3.1), Governance (3.2), Conflict (3.3), and Resilience (3.4). These four categories represent components of the general causality model presented in Figure 2.

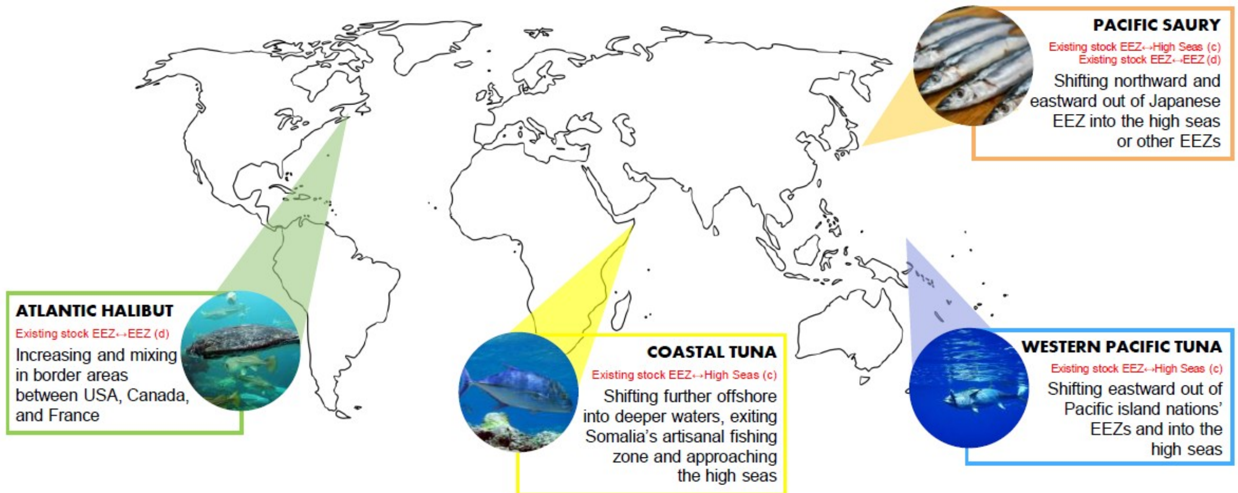

Figure 3 Map of case study locations and general description of climate-driven shifts of key fish species. Red text denotes the archetypes from Figure 1 that map onto each of the case studies.

Table 2 Summarized background information on the current stock status and fisheries management systems of each case study. Information included in the table is drawn directly from the case studies, which can be viewed in detail in supplementary materials. WCPFC = Western and Central Pacific Fisheries Commission, FFA = Pacific Islands Forum Fisheries Agency, IOTC = Indian Ocean Fisheries Commission. Taiwan is also referred to as Chinese Taipei in the supplemental materials.

	Atlantic halibut in the Canadian Shelf	**Tuna in the western and central Pacific**	**Pacific saury in the northwest Pacific**	**Coastal tuna in the Horn of Africa**
Primary species	Atlantic halibut *(Hippoglossus hippoglossus)*	Skipjack tuna (*Katsuwonus pelamis*), Yellowfin tuna (*Thunnus albacare*s), Bigeye tuna (*Thunnus obsesus*) and South Pacific Albacore	Pacific saury (*Cololabis saira)*	Juvenile Yellowfin tuna (*Thunnus albacares*), Skipjack tuna (*Katsuwonus pelamis*), Kawakawa (*Euthynnus affinis*), Longtail tuna (*Thunnus tonggol*), and Indo-Pacific king mackerel (*Scomberomorous guttatus*)
Type of shift	Existing stock shift EEZ↔high seas and EEZ↔EEZ (shift type d)	Existing stock shift EEZ↔high seas and EEZ↔EEZ (shift type c)	Existing stock shift EEZ↔high seas and EEZ↔EEZ (shift type c and d)	Existing stock shift EEZ↔high seas (shift type c)
Primary countries that catch stock	France (via territories of St. Pierre and Miquelon), Canada, United States	Japan, Taiwan, China, Korea, USA and European Union, and by Pacific Island countries where national fleets are often comprised mainly of vessels 'flagged' to some of these distant	Japan, Taiwan, China, Korea, Russia,Vanuatu	Somalia, China, Iran, Yemen, Spain, France, Taiwan

		water fishing nations (DWFNs)		
Relative split of catch among fishing nations	Canada accounts for about 90% of NW Atlantic halibut catch; the US and France combined account for about 1%	95% of the total tuna catch from the EEZs of all Pacific Island states comes from the waters of the eight countries that are the members of the Parties to the Nauru Agreement (PNA)	Japan used to catch the majority of saury stock, but their percent of total catch has been declining since the 1980s. Taiwan now catches the most saury, followed by China and then Japan	In Somali EEZ, Yemen and Iran catch the majority of coastal tunas and juvenile YFT, while Somalia's domestic fleet catches a fair share. In high seas near Somalia, China and Spain currently catch the majority of adult migratory tunas
Economic importance	High for Canada, Low for US	High	Medium	Low, but growing
Cultural importance	Low	High	High	Medium
Market structure & seafood industry	Atlantic halibut caught in Canada is economically valuable, and the stock in Canadian waters is much larger than in US waters. Catch is restricted in US waters and the stock has been depleted for a century, but might become viable as the stock grows in both US and Canadian waters	The majority (~70%) of the total tuna catch is made by purse-seine vessels. DWFN purse-seine vessels, including those flagged to Pacific Island countries, pay access fees to PNA members to catch tuna in their EEZs and sell the fish on the international market. Stock shifts will reduce the purse-seine catch from the combined EEZs of PNA members and decrease the access fees on which they depend.	Saury is mainly caught by Taiwan and China, but sold and consumed mostly in Japan. Chinese consumption is growing as well. Taiwanese catch is mainly exported either to Japan (at a lower cost than domestic Japanese catch) or to other countries for use in canning or as fish meal	Licensed Chinese vessels are targeting adult sized yellowfin, while those targeted by the Somali domestic fleet are juvenile yellowfin or adult coastal tunas. Domestic Somali catch is primarily locally consumed, while Chinese catch is exported and sold elsewhere
Governance structure	Atlantic halibut distribution extends beyond Canada into international high seas regulatory areas, where it is fished by other NAFO countries, and into the Exclusive Economic Zones (EEZ) of the United States as well as into a narrow French EEZ within Canadian waters	The cooperative fisheries management arrangement implemented by PNA in their combined EEZs, known as the vessel day scheme (VDS), contributes to sustainable management of the large tuna purse-seine fishery. The RFMO is the WCPFC, actively supported by the FFA	Japan's Fisheries Research and Education Agency (FRA) is the only country that conducts national stock assessments. The NPFC also has its own set of monitoring and TAC limitations in place that apply to all members	Legislatively, the first 24 nm of maritime domain are reserved for access by Somalis. This is governed by the 2014 Somalia Fisheries Law, which is currently being updated by the Somali Parliament. The IOTC is active in tuna management in this region

	ATLANTIC HALIBUT	PACIFIC TUNA	PACIFIC SAURY	COASTAL TUNA	KEY FINDINGS
CONTEXTUAL FACTORS		•	•	•	**Uneven food security or economic dependence** on a stock between fishing entities can impact bargaining power in determining how the stock is used and distributed
	•	•	•		**Balanced power structures** elevate the importance of negotiation and incentives for conflict avoidance
		•	•	•	**Increased demand** for a species due to new consumer preferences, depletion of other food sources, or lack of substitutes can increase conflict risk
		•	•	•	**Multiple scales of conflict** are possible in cases where internal conflicts (e.g. fisher-fisher) may compound external disputes (e.g. fishing community-foreign industrial fleet)
	•	•	•	•	**Complex history** of internal/external conflict, unequal access, and lack of data can make link between stock shift and conflict less clear. Varied cultural and market importance may lead to **power imbalances**
		•	•	•	Shifts between an EEZ and the high seas shifts increase **management and jurisdictional complexity**
GOVERNANCE	•	•	•	•	Greater **communication and spatial coverage** between RFMOs and member nations may improve collaborative management of increasingly mobile stocks
	•	•	•	•	Incomplete, non-uniform, or one-sided **stock assessments and TAC allocations** contribute to ineffective multi-lateral governance. Lack of **data sharing** between fishing nations and RFMOs also reduces coordination and increases risk of disagreements over equitable allocation
	•	•	•	•	**Absence of conflict mediation clauses** or legally defined enforcement responsibilities in the case of cross-border fisheries conflict suggest uncertainty in how potential conflict would be handled
CONFLICT	•	•	•	•	**Future conflict potential** is modulated by the quality of fisheries management, its flexibility in the face of change, and the magnitude and abruptness of the shift
	•	•	•	•	Likely **'losers' of conflict** are often those who see a stock shifting away from their waters. However, in cases where international laws regarding stock sharing are ignored, the 'loser' could be any country with weaker diplomatic or political standing than its adversary
	•	•	•	•	In the absence of clear **conflict mediation policies**, the winners/losers of potential future conflicts remains difficult to predict
	•	•	•	•	Different conflict scenarios arise depending on the **magnitude of stock shift.** Full exits increase the number of actors and potential conflicts
	•	•	•	•	Changes in **market benefits** as user groups decide whether to follow the fish or transition to alternate industries. **Equity** issues arise as catch distributions and access between local harvesters and DWFNs shift
RESILIENCE	•	•	•	•	Incentivized time investment and representation of **stakeholders** in the solution design process helps ensure uptake and lasting success
	•	•	•	•	**Markets, economic incentives**, and **effective international governance** play a role in shifting power imbalances if designed properly
	•	•	•	•	Collaborative **scientific monitoring** and **climate projection** efforts that cross jurisdictional boundaries are key. Baseline scientific standards still need to be established in many cases
		•	•	•	High **flexibility and mobility** to follow shifting stocks among less empowered actors or capacity for collective action promotes resilience
	•	•	•	•	An individual's **capacity to diversify** into alternate fisheries or industries can build local resilience while also relieving pressure on international agreements

Figure 4 Table of key findings from case study analyses. The relevance of each finding to the individual case study is denoted by the black circles in the left columns. The categorical groupings – Contextual factors, Governance, Conflict, and Resilience – were adapted from the general causal model (Fig. 2).

3.1 Contextual factors

Contextual factors have the potential to strongly influence the scope for conflict. In the western central Pacific, although members of the Parties to the Nauru Agreement (PNA) rely heavily on tuna for government revenue (Bell et al. 2021), rapid population growth in some member countries is expected to increase demand for tuna for local consumption (Bell et al. 2015), creating the need to diversify the way the resource is used. Care will be needed to ensure that such diversification is planned to minimize conflict between small-scale and industrial fisheries within countries (Seto et al. 2023).

Relative power imbalances between the nations sharing a fishery are important indicators of conflict potential (Spijkers et al. 2021). For conflicts between neighboring countries where power and wealth are relatively balanced, such as over halibut fisheries in the adjacent EEZs of the United States and Canada, our case study suggests that the key parties' abilities to negotiate and provide incentives for cooperation appears to be crucial. On the other hand, in the case of Somali coastal tuna, a complex history of power imbalances, intra-national conflicts such as piracy and civil war, unequal access to the resource (and markets), and a lack of data to inform fisheries management, made it difficult to isolate climate change as a major driver of conflict (Glaser et al. 2019).

The Pacific saury case study suggests that increased demand due to new consumer preferences can lead to changes in stock health, resulting in increased conflict. Saury has historically been primarily consumed in Japan as a culturally important dish called Sanma. However, changing consumer preferences – mainly growing demand for Sanma in China – is altering the market structure and predicating larger demand for a saury population that is increasingly shifting into unregulated and industry-heavy high seas waters (Xing et al. 2022, Liu et al. 2022). Demand that is based on traditional Japanese uses may decrease if substitutions are found, but the sociocultural implications of this type of switch are unknown.

3.2 Governance

Governance has the potential to be effective at proactively addressing transboundary stock shifts if designed and implemented properly. In cases where stocks are shifting from an EEZ to the high seas, greater collaboration between member States of the relevant RFMO(s), when they exist (Goodman et al. 2022), will help to dampen negative implications of cross-jurisdictional stock redistributions. Formal mechanisms for coordination may need to be strengthened or established and the capacity of "weaker" RFMOs to effectively govern stocks and come to agreements on harvest control rules should be bolstered. Power imbalances are particularly salient in places where the activities of DWFNs and artisanal fisheries overlap (e.g. Somali coastal tuna). Many RFMOs – such as the Indian Ocean Tuna Commission, or IOTC – have official mechanisms for cross-border collaboration in place, but it is unclear how effective these agreements are and whether data sharing or joint decision making are genuine parts of this process (Løbach et al. 2020). For the PNA vessel day scheme (VDS) in the western central Pacific, long-term effectiveness relies on the continued cooperation of PNA members. This co-operation has been exemplary and extends to the development of 'pooling' and 'roaming' provisions to assist those members located further to the west to retain their allocations of fishing days as tuna are redistributed to the east (Clark et al. 2021). The scope for conflict stems mainly from scenarios where there is substantial redistribution of tuna from the combined EEZs of PNA members to high seas areas within the jurisdiction of the Western and Central Pacific Fisheries Commission (WCPFC), and further east to the jurisdiction of the Inter-American Tropical Tuna Commission (IATTC).

3.3 Conflict

Past examples of fisheries conflict in our case studies have been non-violent (i.e., diplomatic disputes and embargos over western and central Pacific tuna) as well as violent (i.e., unauthorized/forceful vessel boardings or seizures of fishing vessels in waters near Somalia). In these cases, future conflict potential is modulated by factors including: 1) the quality of fisheries management (i.e., the financial and human resources available to effectively implement existing management measures) (Devlin et al. 2021); 2) the system's flexibility (i.e., adaptability) in the face of change (Holsman et al. 2019); and 3) the magnitude and abruptness of the stock shift (Pecl et al. 2017, Palacios-Abrantes et al. 2022). The likely 'losers' of conflict in our cases tended to be those who see a stock shifting away from their waters (in cases where parties adhere to international law). However, in cases where parties choose not to respect international law regarding stock sharing, the 'loser' could be any country with weaker diplomatic, military, or political standing than its competitors.

As demonstrated by the case of tuna in the western central Pacific and the PNA, an important step in proactive conflict avoidance is finding ways to promote collective action and to incentivize engagement in the decision-making process (Adger 2010). Early and consistent stakeholder involvement has been shown to promote collective action and cooperation in broader natural resource management contexts, for example by allowing stakeholders to center concerns such as preserving culturally significant fish stocks or maintaining market value for certain species (Pestoff 2013).

3.4 Resilience

In all cases analyzed here, the countries involved seem to be interested in pursuing international (i.e., collaborative) responses to the shift in fish biomass. However, collaboration can be time consuming, and the pursuit of a fully collaborative management process runs the risk of being outpaced by the ecological changes it is meant to proactively address (Österblom et al. 2020). This lengthy timeline for collaborative decision-making brings issues of equity and justice into play, especially in cases where domestic fleets lose access to subsidized DWFNs as stocks cross boundaries, transferring economic benefits to the countries operating these foreign fleets (Schuhbauer et al. 2020). Moreover, there can be environmental and sustainability concerns over the fishing methods and gears used by DWFN fleets (Okafor-Yarwood et al. 2022, Magyar 2009).

High flexibility and mobility that can allow artisanal small-scale fishers to follow shifting stocks, combined with the capacity for collective action and adaptive fisheries co-management, promotes economic resilience for nations and individual actors (Olsson et al. 2004). For the local fishers themselves, many are attempting to adapt in terms of investments in gears, vessels, or other fishing technologies that would allow them to follow the fish further offshore (Belhabib et al. 2018). Taking the example of Pacific saury, the Japanese fishery could adapt to altered saury distributions by adopting the strategy used by Taiwan, where the country operates a large group of fishing fleets equipped with refrigerated processing and transport ships to allow more distant-water catch (see Supplemental Materials). However, potential consequences of fishing further offshore include higher fuel costs and more time spent at sea – expenses which could be passed on to the consumer through higher priced fish (Jones et al. 2014). For saury, this increased mobility could also potentially elevate geopolitical tensions as the Japanese fleet would likely begin to frequent areas within or near the underregulated high seas.

There may also be trade-offs between individual abilities to continue fishing and international-level resilience of shared governance arrangements (Smallhorn-West et al. 2022). An individual actor's capacity to diversify into an alternate fishery (which requires access to various assets) can build their local resilience while relieving pressure on international agreements to address potential conflicts. In the case of coastal tuna in Somalia, a transition of the artisanal fleet from tuna to demersal species or small pelagics could help domestic fishers diversify their catch and build a local market for these alternate species (Obura et al. 2017). This type of transition would require adjustments to current consumer preferences and market structures, and Somali opposition to IOTC yellowfin tuna allocations would likely persist unless the coastal tuna fishery is abandoned completely.

Atlantic halibut exemplifies a case where warming ocean conditions may lead to an increase in fish abundance that, when coupled with an effective management framework, could benefit the fishing industry. In this case, the stock is expanding its territory as opposed to undergoing a poleward shift or a shift to deeper waters, as occurs for some other transboundary stocks. This expansion is occurring in terms of both population size and distribution, meaning that, for now, more fishers could have access to a larger population of halibut as waters continue to warm.

Markets and economic incentives could also play a role in encouraging disputing parties to reach consensus. For example, a requirement of eco-certification schemes, such as the Marine Stewardship Council, is that the whole stock is managed under a coherent harvest strategy, which will require, among other things, data sharing and monitoring control and surveillance agreements across the parties sharing the stock. Failure to meet these requirements can result in a loss of certification for a fishery, as was the case with Atlantic mackerel during the years-long period of non-cooperation over allocation (Hønneland, G. 2022).

Another example of potential market incentives can be seen in the Somali tuna case study: if DWFNs are incentivized to land tuna in East African ports instead of transhipping the fish to foreign markets, the economic benefits of the resource would stay within East Africa, reducing unequal gains (see Supplemental Materials). One potential method of achieving this is through port infrastructure and cold chain improvements to facilitate more local landings and processing, and to meet the needs of fishing companies to service and repair vessels and fishing equipment.

3.5 Synthesis Model

The individual case study causal models (provided in Supplemental Materials) and the original causal model from the workshop (Fig. 2) have been synthesized in Figure 6 to visualize the range of conflict formation or avoidance pathways observed in the four case studies. This synthesis model separates the initial response of a system to transboundary stock shifts into three categories: non-cooperative, adaptive, or cooperative responses. These responses can be carried out by actors and institutions at various levels within the system, including fishers, fleets, scientific bodies, national management bodies, and international management bodies. Examples of **non-cooperative responses** include: increased IUU fishing, overexploitation of stocks in new or altered fishing grounds; or incursion of foreign fishing vessels into border zones or EEZs. Examples of **adaptive responses** include: transition to an alternate fishery or substitutes; altering the allocation system to account for new distributions and adopting placating mechanisms such as side payments; or adapting the fishing fleet to 'follow the fish'. Examples of **cooperative responses** include: cross-border cooperation, co-management between RFMOs or other international organizations, or data sharing. In all cases, these responses are influenced by the governance structures and contextual factors that provoke or prevent the formation of conflict.

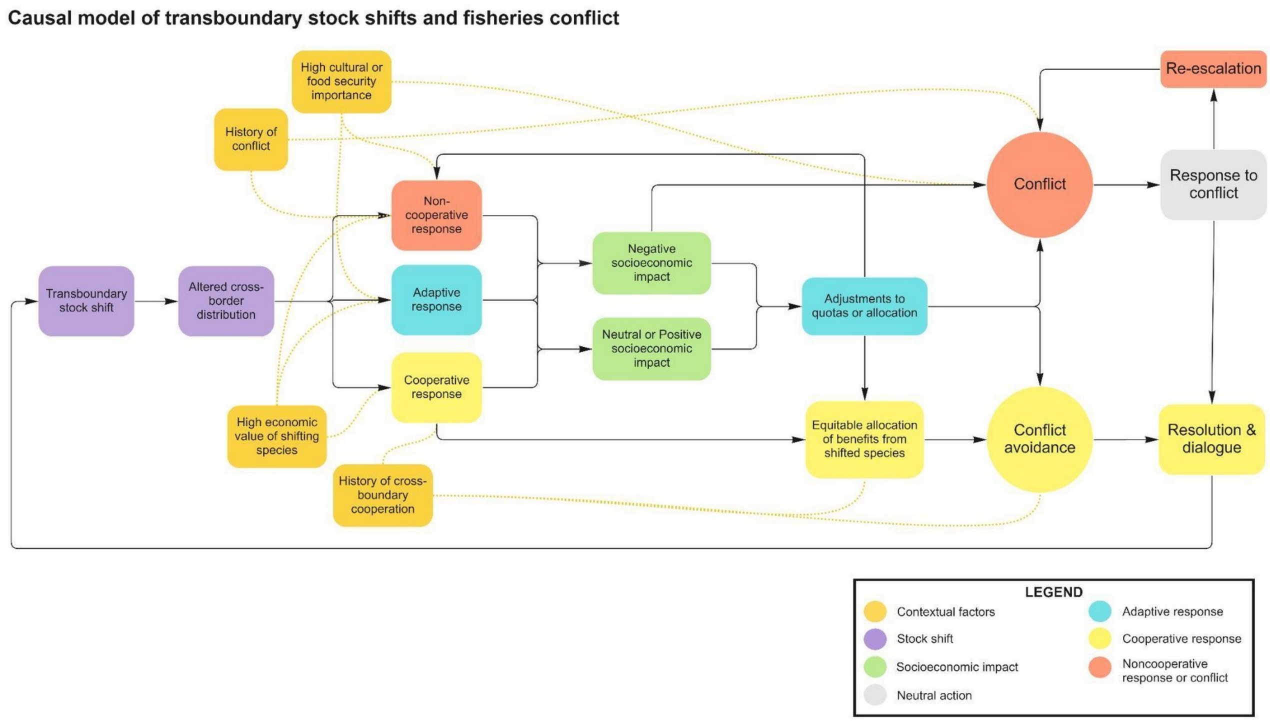

Figure 5 Synthesis Model of transboundary stock shifts and fisheries conflict. This model combines key findings from the four individual models derived from the context-specific case studies provided in the supplementary materials.

The responses visualized in the Synthesis Model are not mutually exclusive and can co-exist at different scales in a fishery system, depending on the cohesiveness and level of acceptance of the response. For example, in the case of coastal tuna in Somalia, the multi-national governance system (the IOTC) could adopt a **cooperative** response and effectively implement a catch allocation scheme between the Somali fleet (and other coastal states) and distant water fishing nations (DWFNs), as is currently under discussion. At the same time, the artisanal Somali fleet could pursue an **adaptive** response and transition to demersal fishing as a replacement for tuna (given gear and technical availability). Despite these cooperative and adaptive responses, conflict could still arise as a result of **non-cooperative** responses elsewhere in the system, such as increased IUU fishing targeting cooperatively allocated tuna.

The Somali example highlights the purpose of this figure: it is not a prescriptive overview of exactly how conflict will form in every stock shift scenario. Instead, it is meant to provide insight into the complexity of conflict formation in shifting transboundary fisheries, and to highlight the initial response stages where inclusion of proactive and cooperative measures can greatly improve a system's resilience to conflict.

Furthermore, adaptive responses, such as transitioning away from a shifted fishery or following the fish to their new preferred areas, can lead to either conflict formation or avoidance. For example, in the Pacific saury case, the potential adaptation of the Japanese fleet to follow saury into their new preferred habitat could result in increased interactions (and potential conflict) between Japanese and Chinese vessels in fishing grounds near the Japanese EEZ. Conversely, should the Japanese fleet decide against following the fish further offshore, there would be a shift in the flow of revenue from fishing activities, and potential alterations to the price of saury in Japanese and other consumer markets.

4. Discussion

The predominant type of transboundary shift described in our case studies is that of existing stocks shifting away from EEZs to the high seas (archetype c). This type of shift can result in more complex management situations than EEZ-EEZ shifts given that the governance system of the high seas is completely different than that of EEZs, including generally weaker rules and monitoring of access (Crespo et al. 2019) and the consensus-based decision-making process of many RFMOs (Haas et al. 2022).

It is important to note this study's omission of any cases that deal with "novel stock shifts" (i.e., stocks shifting into a jurisdiction where they were not previously present and/or managed), either between EEZs or between the high seas and an EEZ (archetypes a and b). This suggests that in some cases where a stock shift is technically novel (e.g., the stock has not historically been present within an area in any measurable quantity), it is not perceived as novel by those who manage or study the stock. Fisheries managers may consider a stock to be pre-existing within their waters even when it is not for a variety of reasons, including uncertainty or disagreement over jurisdictional boundaries at sea, or knowledge of stock presence in nearby areas and assumed expansion into other waters as well.

A famous example of novel stock shifts and conflict is that of northeast Atlantic mackerel and the lengthy "mackerel wars" that arose over the seemingly sudden and novel appearance of mackerel in Iceland and Greenland waters in 2007. This particular conflict has received ample attention in the academic literature (Spijkers & Boonstra 2017, Østhagen et al. 2020, Gray 2021, Jensen et al. 2015) and was purposefully omitted from this study. However, this case must be mentioned in the discussion of novel vs. existing shifts, because this transboundary shift led to the formation of new fisheries in Iceland and Greenland for a stock that had previously been absent, and engendered a decade-long international conflict and subsequent trade war over allocation between the European Union (EU), Norway, Iceland, and the Faroe Islands (Østhagen et al. 2022). This case highlights the role of relative time horizons and the potential for varied perceptions of a stock's status as either abruptly appearing in a new area (i.e., novel) or gradually transitioning across a boundary (i.e., existing) on the likelihood of conflict avoidance or formation.

It is important to also highlight the deficiencies of the methodological approach adopted in this paper. We relied on expert elicitation and collective knowledge-production with a group of around 30 experts. This group resides overwhelmingly in the northern hemisphere and although two of the case studies were centered on developing country regions (Western central Pacific tuna and Somali coastal tuna) we acknowledge that further research and case studies would benefit from greater representation of scientists and managers from other regions.

One of our hypotheses was that a combination of *novel* stock appearance or disappearance across international boundaries would create the highest risk of potential conflict, as was the case with northeast Atlantic mackerel. We are unable to evaluate this hypothesis due to our lack of case studies that represent this scenario, but further studies might explore whether factors such as incongruous baselines or incidental catch at the leading edge of a shifting stock might be responsible for the tendency to perceive these seemingly novel stocks as pre-existing.

Our case studies illustrate that a likely driver of conflict is stock migration into high seas waters where artisanal and small-scale fishers lose access and DWFNs gain access (Pomeroy et al. 2016). The presence of foreign fishing vessels in or near the EEZs of countries that are losing stocks has high potential for conflict at a variety of scales and intensities. This can be seen in the case of coastal tuna in Somalia, where fish moving out of the 24 nm artisanal zone leads to increased access to coastal tuna by the foreign fishing fleets of nations operating within the remainder of the EEZ, such as China and Iran. Conflicts may increase between Somali artisanal fishers and DWFNs, between Chinese fishers and other DWFNs as stocks move into high seas waters, or between Somali fishers as their share of overall catch decreases (Devlin et al. 2021).

Throughout our cases, effective international governance and strong science capacity emerged as key enabling factors for strengthening resilience of existing management arrangements to climate-induced shifts in fish stock distribution and abundance, consistent with theorized frameworks of climate resilience in fisheries (Cinner et al. 2019, Mason et al. 2021). However, for this to be applied more broadly, international governing bodies (e.g., RFMOs) would need to prioritize modeling of the effects of climate change on shared stocks throughout their distribution, and collaborative monitoring of shifts across jurisdictional boundaries. In many cases, establishing baseline standards for stock monitoring and data sharing may be required to promote shared understanding of climate impacts on stock dynamics.

Going forward, mechanisms to avoid and resolve conflict via timely management decisions should be identified and implemented, even when there is uncertainty in current and projected stock status and distribution. Conflict avoidance and resolution will likely benefit from more advanced climate modeling and comprehensive long-term monitoring. The centrality of equity and justice concerns in every step of the fisheries management cycle also needs to be recognized and integrated into procedures for building resilience (Bennett 2022). There is no climate justice without human rights (Schapper 2018), so concomitant issues such as food security, livelihood security, and distributive justice ought to be emphasized in any efforts to increase resilience of fishers and communities to transboundary stock shifts (McClanahan et al. 2013).

We also recognize that 'good governance' and proactive management are not always enough. There are sure to be cases where the magnitude or intensity of a stock shift predicates a completely new way of governing transboundary stocks, which will require further study to inform effective negotiations aimed at avoiding or resolving conflict.

5. Conclusion

This analysis suggests that a failure to prepare for the impacts of a changing climate has potential to increase the incidence and severity of fishery conflicts and other negative consequences for fisheries, dependent communities, food security, and international relations. Although the degree to which climate change will increase or exacerbate fisheries conflicts in the future is uncertain, we know climate change is altering the distributions of fish stocks on a global scale and conflicts have already emerged – lending urgency to efforts to better understand the connections between these shifts and geopolitical consequences, such as conflict.

The case studies we have documented highlight regions where climate-driven shifts in the distribution of important fish stocks are already leading to important challenges, and demonstrate governance mechanisms that can reduce the potential for conflict while promoting sustainable, equitable, and resilient fisheries. These case studies point to the relevance and consequences of transboundary stock shifts for communities, fishing industries, non-fishing industries, national governments, and international organizations around the world.

In the near future, priority areas for research and policy action include building tools for evaluating the potential for climate-induced conflict, developing effective responses to the challenges posed by climate-induced stock shifts, and advocating and negotiating for the changes required to implement these responses in specific fishery systems. Expanding the list of case studies included here to address cases of the two absent archetypes - novel stock shifts from EEZ to EEZ and from EEZ to high seas - from around the world will enable the full spectrum of tools and mechanisms for reducing conflict to be developed.

6. Acknowledgements

We'd like to thank Marta Ballesteros for her thoughtful revisions and contributions to the final draft of the paper.

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