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The Northwest Atlantic Fisheries Organization Roadmap for the development and implementation of an Ecosystem Approach to Fisheries: structure, state of development, and challenges

Mariano Koen-Alonso[a,*], Pierre Pepin[a], Michael J. Fogarty[b], Andrew Kenny[c], Ellen Kenchington[d]

[a] Northwest Atlantic Fisheries Centre (NAFC), Fisheries and Oceans Canada (DFO), St. John's, NL, Canada
[b] Northeast Fisheries Science Center (NEFSC), National Oceanic and Atmospheric Administration (NOAA), Woods Hole, MA, USA
[c] Lowestoft Laboratory, Centre for Environment Fisheries and Aquaculture Science (CEFAS), Lowestoft, UK
[d] Bedford Institute of Oceanography (BIO), Fisheries and Oceans Canada (DFO), Dartmouth, NS, Canada

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ABSTRACT

The Northwest Atlantic Fisheries Organization (NAFO) Roadmap is the general framework aimed toward implementing an Ecosystem Approach to Fisheries (EAF) in NAFO. The core principles are: a) the approach has to be objective-driven, b) it should consider long-term ecosystem sustainability, c) it must be place-based, and d) the consequences of trade-offs in managing human activities have to be explicitly defined. The Roadmap is not a fixed plan; it evolves as different components are developed, refined, and implemented. Core elements of the Roadmap include the identification of ecosystem-based management units, a hierarchical approach to define exploitation rates by considering ecosystem, multispecies, and stock level sustainability, and the integration of impacts on benthic communities. The modular design of the plan has allowed NAFO to start implementing some components (e.g. closures to bottom fishing for the protection of Vulnerable Marine Ecosystems), while work on others is still ongoing (e.g. multispecies modelling). Even though the Roadmap is far from being fully implemented, NAFO has made important progress towards EAF over the last decade. This paper summarizes the Roadmap structure and the current level of implementation, describes some of the challenges faced, and examines those still ahead.

1. Introduction

The last 30 years have seen a rapidly growing global recognition that sustainable use of marine resources requires integrated approaches, and discussions on fisheries sustainability have often been a kernel from which the conversation has broadened into more encompassing views on how people rely upon and impact the marine environment. Oceans provide a multiplicity of ecosystem services (e.g. wild harvesting and aquaculture, energy and non-renewable resource exploitation, transportation, recreation, contributions to cultural identities, nutrient recycling, carbon sequestration, climate regulation), and given the increasing and diversifying use of marine environments, the need for management approaches that can integrate human activities without hindering ecosystem functionality can only become greater in the future [1].

Despite this worldwide awareness on the need for integrated management of marine systems, and the continuous push by the global community through international agreements and United Nations General Assembly (UNGA) resolutions, widespread progress on the ground remains somewhat elusive. Even within the more constrained realm of fisheries management, most jurisdictions still rely on single-species approaches [2], although some are gradually moving into ecosystem-based strategies for the management of their fisheries [3–7], and the last 10 years have produced important advancements on how to approach and develop integrated fisheries management plans [8–10].

Most examples of progress towards integrated fisheries management typically involve a single jurisdiction (a single country, e.g. USA, Australia), bilateral arrangements (two countries, e.g. Norway and Russia on the Barents Sea), or multiple countries sharing common legal instruments (e.g. The European Union), and often deal with ecosystems within the Exclusive Economic Zones (EEZs) of the coastal states involved [2,6,7,11–13].

On the high seas, outside EEZs, fisheries are managed by Regional Fisheries Management Organizations (RFMOs) or arrangements (RFMAs). Although some regional fisheries bodies have a long history, their effectiveness in managing fisheries resources has often been

* Corresponding author.
E-mail address: Mariano.Koen-Alonso@dfo-mpo.gc.ca (M. Koen-Alonso).

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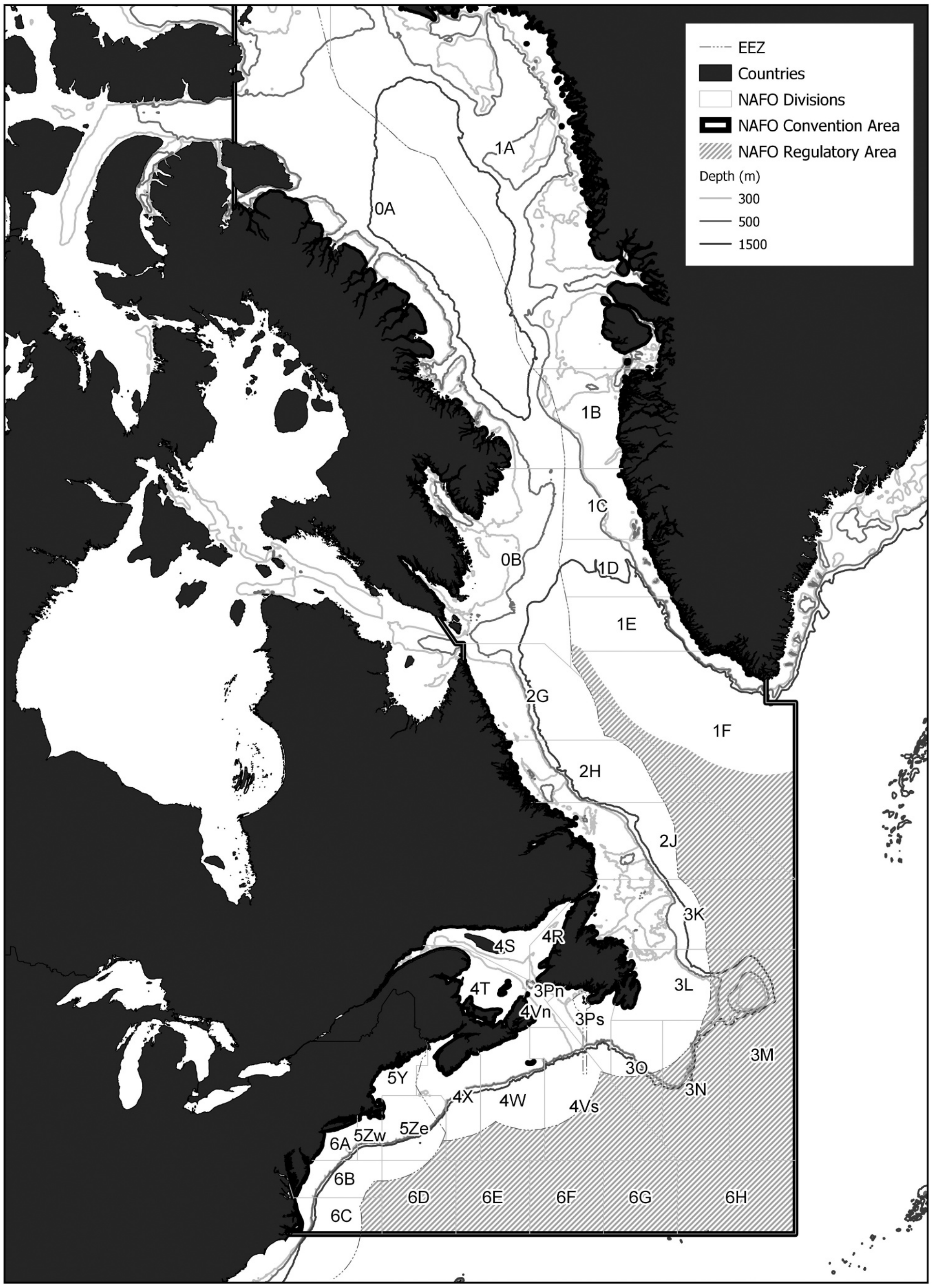

Fig. 1. NAFO Convention Area, where the NAFO Regulatory Area (NRA) is highlighted (shaded area), and with indication of NAFO Sub-Areas (numbers), Divisions (uppercase letters) and Sub-divisions (lowercase letters).

questioned [14–16]. However, RFMO/As are modernizing their frameworks and practices [17], trying to adapt to new realities demanding the protection of Vulnerable Marine Ecosystems (VMEs), conservation of biodiversity in Areas Beyond National Jurisdiction (BBNJ), and the implementation of precautionary and ecosystem approaches. Still, and despite recent advances, delivery on these goals remains a challenge [18].

In this context, the objectives of this paper are to describe the template that one RFMO, the Northwest Atlantic Fisheries Organization (NAFO), is currently following to implement an Ecosystem Approach to Fisheries (EAF), provide a synoptic summary of the progress to date, and discuss some of the challenges faced and the ones still ahead.

2. NAFO: origins, vision, and governance

NAFO is the RFMO responsible for the management of fisheries resources within the NAFO Convention Area (Fig. 1) outside coastal states EEZs in the Northwest Atlantic, that is, the NAFO Regulatory Area (NRA). The fisheries resources under NAFO management include fish stocks inhabiting the NRA as well as several straddling stocks (Table 1). NAFO was created in 1979 to replace a pre-existing body, the International Commission for the Northwest Atlantic Fisheries (ICNAF), which managed fisheries in the Northwest Atlantic between 1949 and 1978. In 2007, NAFO amended its convention to modernize the organization and adopt an ecosystem approach to fisheries management.

Table 1
Northwest Atlantic stocks under NAFO management. SA: Sub-Area.

Species	Management stocks
Atlantic cod	3M, 3NO
American plaice	3M, 3LNO
Redfish	3M, 3LN, 3O
Greenland halibut	SA2 + 3KLMNO
Yellowtail flounder	3LNO
Witch flounder	2J3KL, 3NO
White hake	3NOPs
Thorny skate	3LNOPs
Capelin	3NO
Northern shrimp	3M, 3LNO
Squid	SA3 + 4

After a long ratification period, these amendments came into force in 2017.

As stated in its convention, NAFO's objective is to *ensure the long term conservation and sustainable use of the fishery resources in the Convention Area and, in so doing, to safeguard the marine ecosystems in which these resources are found*. The convention recognizes *the economic and social benefits deriving from the sustainable use of fishery resources*, promotes *the long term conservation and sustainable use of the fishery resources based on the best available scientific advice and the precautionary approach*, and **commits** to *apply an ecosystem approach to fisheries management in the Northwest Atlantic that includes safeguarding the marine environment, conserving its marine biodiversity, minimizing the risk of long term or irreversible adverse effects of fishing activities, and taking account of the relationship between all components of the ecosystem*.

NAFO governance is organized around two main constituent bodies, the Scientific Council (SC), which is responsible for the assessment of fisheries resources and the provision of scientific advice, and the Commission (COM), which is responsible for taking management decisions. The NAFO annual management cycle revolves around two main meetings, one focused on the production of the science advice, and the other on making management decisions (Fig. 2a). All management measures adopted by NAFO are incorporated into the NAFO Conservation and Enforcement Measures (NCEM), which are updated every year and come into effect on January 1 of the following year. Both SC and COM rely on subsidiary groups (e.g. Standing Committees and Working Groups) in charge of performing specific tasks and analyses which are delivered to and reviewed by the corresponding parent body (Fig. 2a).

3. The NAFO Roadmap to EAF

Since the ratification procedure for the amended NAFO convention started in 2007, NAFO has been engaged in a process to develop and implement an EAF for the organization. The template being followed is commonly known as the 'Roadmap'.

The core premises of the Roadmap are: a) the approach has to be objective-driven, b) it should consider long-term ecosystem sustainability, c) it must be place-based, and d) the consequences of trade-offs in managing human activities have to be explicitly defined. Building upon the concept of Integrated Ecosystem Assessments (IEAs) [8] as the analytical tools to evaluate management options within integrated fisheries-ecosystem management plans [9], the Roadmap defines a recursive path with scientific information feeding into the management process, where its use leads to adapting ecosystem objectives and/or management practices, generating a feedback into the science process that further hones the research and science advice required to aid management decisions. The Roadmap is intended to be adaptable by providing a basic structure and general principles on which to build an EAF for NAFO and whose details evolve as it is developed and implemented.

As concluded by Soomai [19], the credibility and legitimacy of the scientific information and advice for decision-making depends on formal processes for information production and communication, which in most fisheries management organizations favour traditional fisheries management and are not well equipped to include ecological considerations and climate change. Therefore, developing and implementing an EAF framework requires not just dedicated research, but also developing the trust among different players (e.g. scientists, managers, stakeholders) that will lend credibility to the ecosystem-based advice, and to develop and/or modify the existing formal pathways to better incorporate different types of information into the decision-making process.

For these reasons, the Roadmap was designed as a modular approach, so that the information generated at each step could be used as it becomes available. This modularity contributes to a gradual transformation of management practices, allowing for the time required by the organization to learn and adapt. It also allows the development of the framework to adapt to the available resources, research capacity, and management priorities.

At present, the Roadmap does not explicitly incorporate socio-economic and cultural elements into the EAF process. Existing single-species science advice in NAFO does not include socio-economic considerations, but NAFO Contracting Party (CP) delegations to the COM include stakeholder representation and their input influences the official positions that CPs adopt during the formal COM decision-making process. The conversation within NAFO on how moving into EAF would affect the way in which socio-economic and cultural issues should be considered has yet to be had. In its current phase, the Roadmap has been focused on the ecological aspects of EAF.

The ecological foundation for the Roadmap considers ecosystems as nested hierarchical structures that integrate biological, chemical, and physical processes operating at different temporal and spatial scales [20]. Higher level structures would affect lower level ones, acting as constraints to the levels within [20]. Therefore, addressing ecosystem

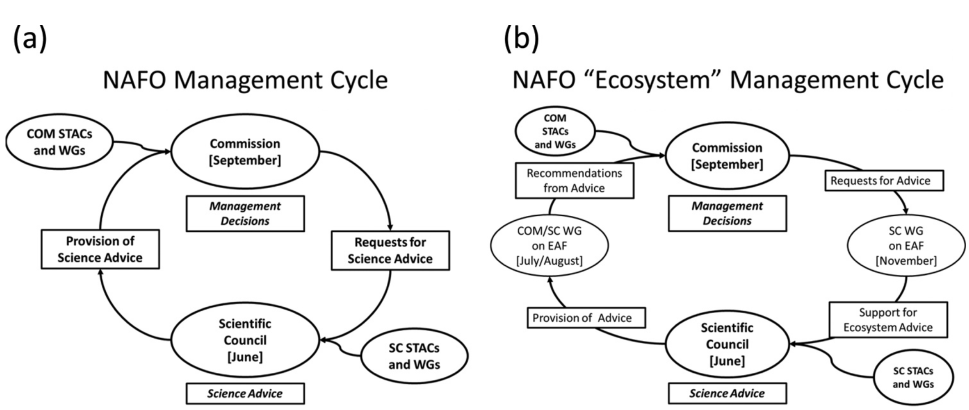

Fig. 2. NAFO Annual Management Cycle. a) Standard depiction of the management cycle highlighting main Scientific Council (SC) and Commission (COM) meetings; b) "Ecosystem" management cycle, highlighting the main steps for current advice and decision making involving ecosystem issues, including the development and implementation of an ecosystem approach. STAC: Standing Committee, WG: Working Group.

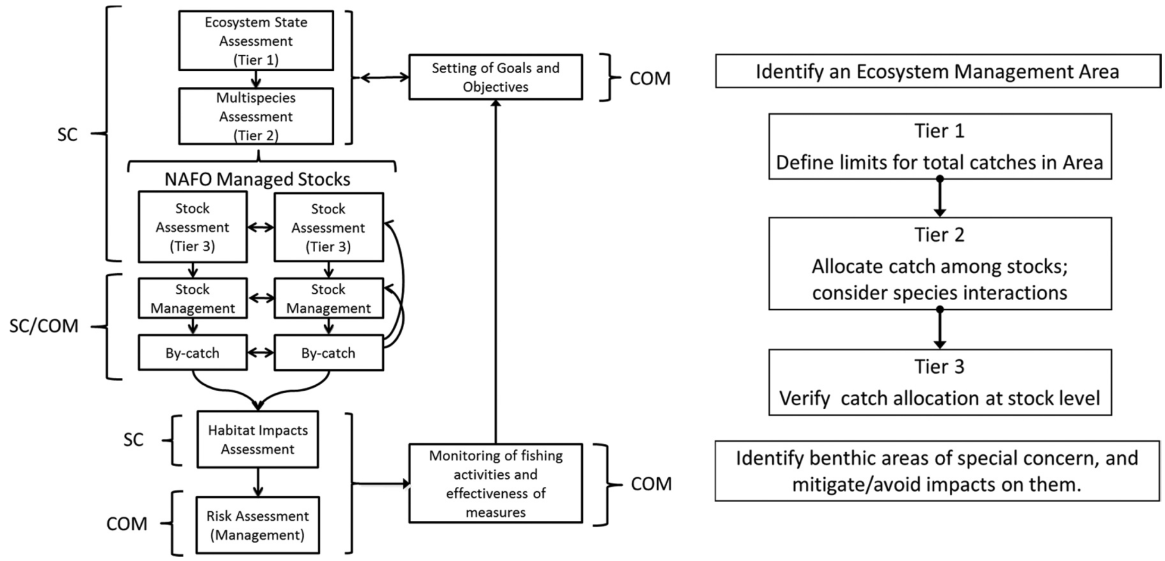

Fig. 3. Current working template of the NAFO Roadmap (left), with a synoptic overview of the key steps required for using it (right). SC: Scientific Council, COM: Commission. The labelled vertical brackets indicate the leading NAFO body for the different roadmap components.

sustainability requires geographical boundaries that are consistent with the spatial and temporal scales of the set of interacting marine fish stocks to be managed together, while considering what factors regulate and constrain ecosystem productivity at those scales (e.g. [21]). In practical terms, this can be tackled as two complementary and interrelated components. The first one uses our understanding on environmental and ecological interactions to define exploitation rates which are sustainable and consistent among themselves for the suite of target stocks within a functional ecosystem unit. The second component is the consideration of the unwanted impacts of fishing on non-target elements within the exploited ecosystem (e.g. by-catch, perturbation on benthic communities and habitats), and how these could affect ecosystem state and processes. These two components can be dubbed as a) the effects of the ecosystem plus fishing on the target stocks, and b) the effects of fishing on other ecosystem elements.

The Roadmap addresses the effects of the ecosystem plus fishing on the target stocks by defining sustainable harvest rates through a three-tiered hierarchical approach, which sequentially considers sustainability at the ecosystem, multispecies and stock levels (Fig. 3, Table 2).

The first tier focuses on the identification of the ecosystem management areas. This stage includes an assessment of ecosystem state and the estimation of fisheries production potential at the functional ecosystem unit level. This allows consideration of large scale climate and ecological forcing, and the fundamental limitation imposed by primary production on fisheries productivity [22–29]. In practice, this stage defines limits for total catches at the ecosystem level that should not be exceeded [28–30]. The concept of defining caps for total catches in an ecosystem is not new in NAFO; ICNAF, its predecessor, had already explored this concept in the 1970s [31,32], and recent reviews of this idea further highlight its value as a fisheries management tool (e.g. [33]).

The second tier (Fig. 3, Table 2) is the stage where models of multispecies interactions would be used to inform the allocation of fisheries production among a set of target stocks, taking into account predation and competition and their potential impacts on the capacity of the exploited marine community to respond to perturbations (i.e. ecosystem resilience) (e.g. [34–36]). This stage considers trade-off among fisheries, and identifies harvest rates which are consistent with multispecies sustainability (e.g. [28,37–39]). This tier also permits incorporating ecosystem objectives beyond harvesting (e.g. maintenance of ecosystem resilience through conservation of biodiversity, minimizing impact on threatened species). In practice, the multispecies analyses in Tier-2 evaluate exploitation scenarios (e.g. portfolios of Total Allowable Catches) derived from management objectives, but which should be consistent with the limits for total catches derived in Tier-1.

The third tier (Fig. 3, Table 2) involves single-species stock assessment, where the harvest rates derived in Tiers 1–2 are further examined to ensure single-species sustainability. The level of resolution of the models used in Tiers 1–2 (e.g. modelling functional guilds, lack of age structure in models, implicit characterization of recruitment processes) may not be sufficient to capture all relevant stock-specific features, and potentially opens the door for unintended impacts on a given species. Tier-3 analyses are intended to address this through the use of precautionary approach frameworks and harvest control rules. As the higher-level tiers develop, they may need to be revised depending on the assumptions and considerations used when they were originally constructed [40]. This tier also recognizes that not all managed stocks would necessarily have strong trophic linkages, and in those cases, harvest rates would have to be defined directly from the single-species assessment but subject to the constrains informed by the limits on total catches and technical interactions.

Taken together, exploitation levels are defined by sequentially examining sustainability at nested levels of ecological organization. A common result from comparing yields from single-species and multispecies analyses is that multispecies yields are often less than the sum of single-species ones (e.g. [41–44]). By examining constraints on harvest rates from the whole ecosystem to the stock level, the Roadmap emphasizes the need of ensuring overall ecosystem sustainability before focusing on individual stocks, and embeds the precautionary principle at the core of the process of defining sustainable harvest rates.

Complementary to this 3-tiered process, the Roadmap addresses the effects of fishing on the ecosystem by focusing on both by-catch and impacts on benthic habitats. While some fisheries can be more impactful than others, the full extent of fishing impacts on the ecosystem is cumulative in nature, and hence, their evaluation requires integration across all fisheries operating within a functional ecosystem unit.

By-catch is one of the first ecosystem impacts of fishing for which management measures were developed. Incidental catches of species with conservation concerns (e.g. marine mammals, seabirds, turtles, sharks), as well as the catch of commercial species under moratoria, are issues of concern in most fisheries around the world. NAFO regulations for some operational interactions were already in place before the Roadmap, while others are linked to its development. Unwanted

Table 2
Brief description of the Roadmap components.

Component	Tasks
Goal setting	• Definition of ecosystem level objectives for the NAFO fisheries
Ecosystem State Assessment (Tier-1)	• Definition of spatial management units. • Exploration of temporal variability of ecosystem units. • Definition of productivity state of the ecosystem and its variability • Provision of advice on limits for total catches for the ecosystem unit.
Multispecies Assessment (Tier-2)	• Description of species interactions and trends. • Quantification of diets and predation. • Understanding the role of environmental drivers in ecosystem structure and dynamics. • Understanding the response of food webs to anthropogenic impacts. • Definition of multispecies reference points. • Provision of advice on catch portfolios based on multispecies considerations.
Stock Assessment (Tier-3)	• Stock identification. • Assessment of the status of the stock. • Consideration of processes/environmental drivers affecting recruitment, growth, maturation and spatial distribution. • Consideration of sources of mortality at the stock level. • Provision of advice on stock-specific catch levels based on Tiers 1–3.
Stock Management	• Definition of stock-level reference points. • Development and implementation of harvest control rules, stock-specific management strategy evaluation frameworks and rebuilding plans.
By-catch	• Evaluation of by-catch of commercial and non-commercial species (including VME-defining species). • Reporting of bycatch for use in all assessments (ecosystem, multispecies, stock, and habitat impacts). • Development and implementation of measures to control by-catch levels.
Habitat Impacts Assessment	• Identification of benthic areas/habitats of special concern (e.g. VMEs). • Characterization of the habitat, its functionality, and its capacity to tolerate perturbations. • Identify and define the nature of the pressures acting on the habitat. • Evaluate impact as a combination of the features of the habitat and cumulative pressures. • Analysis of fishing impacts on benthic ecosystems. • Provision of advice on Significant Adverse Impacts (SAI) on habitats (e.g. VMEs) by fishing activities.
Risk Assessment	• Assess the likelihood of significant adverse impacts on habitats (e.g. VMEs), in the context of current activities and objectives. • Assess the likelihood of fisheries having significant adverse impacts on ecosystem structure and function. • Development and implementation of management actions in response to the outcomes of risk assessments.
Monitoring	• Collection, analysis, and interpretation of data pertaining to ecosystem status and human activities relevant to the NAFO convention objectives. • Use of available data to track the effectiveness of management measures.

catches with regulations in place include the catch of target species below their minimum size requirements, by-catch of fish species under moratoria, as well as by-catch of sharks and VME-defining species. These regulations include reporting duties through CPs and the NAFO Observer Program, by-catch limits for species under moratoria, as well as move-on rules when the fractions found in individual hauls are above predefined thresholds. Irrespective of the Roadmap, these types of measures constitute useful tools to address operational interactions that pose conservation risks. These measures are reviewed as required, and there are ongoing efforts within NAFO to improve catch estimates in general [45], but by-catch regulations typically constitute targeted solutions for fisheries-specific interactions. The Roadmap aims to incorporate such tools into its framework, while integrating across all losses to renewable resources, and which need to be considered in the context of limits to total catches at the ecosystem level.

Likewise, impacts on benthic habitats can only be fully addressed in terms of the integrated losses resulting from fishing practices. Each fishery may have quantitatively and qualitatively different impacts owing to the target species, gear, and modes of operation, but the overall impact on benthic habitats is defined by the cumulative effects of all fisheries operating in a particular region (Fig. 3, Table 2). These impacts would have different long-term consequences depending on the vulnerability of the habitat being perturbed, as well as the role of those habitats for overall ecosystem functioning. Currently, the Roadmap approaches habitat impacts through an evaluation of Significance Adverse Impacts (SAIs) on VME habitats by following Food and Agriculture Organization (FAO) guidelines [46]. SC's evaluation of SAIs constitutes the basis for a COM managers-led risk assessment on the need for spatial management measures to protect critical habitats (Fig. 3, Table 2). As the Roadmap continues developing, these habitat impacts assessments could be broadened to consider other habitats beyond VMEs.

In summary, the Roadmap requires for each geographically defined functional ecosystem unit, the development of a series of interconnected assessments aimed at different spatial scales and levels of ecological organization, which can be schematically described as ecosystem state, multispecies, stock, and habitat impacts assessments (Fig. 3, Table 2). These assessments require the implementation of models and analyses aimed at defining total ecosystem catch levels, exploring ecological trade-offs among exploited species, defining the status of each exploited stock, and evaluating the cumulative impacts of fishing on benthic habitats. However, these assessments should not be simply equated to specific models. There is a diverse range of models that can be used [5,47–53], and each assessment level can (and ideally should) use multiple modelling approaches (e.g. traditional multimodel inference, management strategy evaluation and associated management procedures), as well as a suite of companion analyses required to put any model result in context. Some of these complementary analyses, like identification of environmental regime shifts, trends in community structure, diet studies, estimations of food

Table 3
Basic spatial scales identified for ecosystem summaries and management plans in the context of developing and implementing Ecosystem Approaches to Fisheries Management.

Name	General operational description	Examples in NAFO Convention Area
Bioregion	Large geographical area characterized by distinct bathymetry, hydrography, and which contains one or more reasonably well defined (but still interconnected) major marine communities/food web systems.	• Newfoundland and Labrador Shelves • Flemish Cap • Scotian Shelf • US Northeast Continental Shelf
Ecosystem Production Unit (EPU)	Within a bioregion, a major geographical subunit characterized by distinct productivity and a reasonably well defined major marine community/food web system.This spatial scale is the one generally considered best suited for the development of integrated ecosystem management plans.	• Newfoundland Shelf (2J3K) • Grand Bank (3LNO) • Flemish Cap (3M) • Georges Bank
Ecoregion	Within an EPU, geographical area with consistent physical and biological characteristics. Often corresponds to a broadly defined seascape and/or major habitat type/class; its precise delineation and extent can vary depending on data availability and the analytical criteria applied. It is within this spatial scale that more precise habitats can be identified (e.g. VMEs).	• Inshore areas in the Northeast Newfoundland Shelf • Northern region of the Grand Bank (~3L) • Top of the bank in Flemish Cap • Slope areas

consumption, among other ecosystem indicators, are also integral components of these assessments.

4. Progress towards implementing EAF

Since the mid-2000s NAFO has taken important steps towards EAF. The most evident progress has involved research towards building the natural science underpinnings of the Roadmap, however, less obvious changes involving how the organization operates are also shaping the information generation and communication in ways that contribute towards EAF implementation.

Since the Roadmap is a place-based framework, a foundational piece was to define the spatial boundaries of the functional ecosystems intended to be managed in an integrated way. Building upon existing biogeographical frameworks and community composition analyses [54–58], the process of identifying ecosystem units was based on a suite of physiographic, oceanographic and biotic variables, which were integrated using multivariate analyses [59–65]. Several regional studies were carried out for the Northeast US Continental Shelf [66,67], the Newfoundland and Labrador Shelves [68,69], the Flemish Cap [70], and the Scotian Shelf [71], and then integrated at the Northwest Atlantic scale [72]. On this basis, three nested spatial scales deemed useful for different aspects of ecosystem-level planning were identified: bioregion, Ecosystem Production Unit (EPU), and ecoregion (Table 3) [65,72,73], with the EPU scale emerging as the best suited for integrated ecosystem management plans (Fig. 4). Even though EPUs do not represent closed systems, they generally correspond well with the spatial extent of major groundfish stocks, have a coherent fish community structure, and as a first approximation it can be reasonably assumed that the bulk of the production within the EPU is generated within its boundaries, allowing for the estimation of limits for total catches at the EPU scale.

In terms of ecosystem state assessments, work towards defining ecosystem-level caps for total catches has been primarily based on Ecosystem Production Potential (EPP) models [29,30,63–65,74], complemented with aggregate biomass production models [62]. Initial results for the Flemish Cap, Grand Bank, and Newfoundland Shelf EPUs have been used to develop guidelines for total catches for these areas [65,73,75]. Even though COM has yet to use these guidelines in decision-making, this information is now regularly provided to managers [76,77], and the dialogue between scientists and managers on how best to use them is ongoing [78]. Together with these models, analyses of overall ecosystem structure, trends, and oceanographic regimes provide additional support for describing ecosystem state [60–65,79–81], and have served to identify reduced productivity conditions in some EPUs [82]. These analyses have triggered requests for advice from COM on how ecosystem advice compares to single-species stock-assessment, including additional factors to be considered and integrating trophic level interactions and climate change predictions [83].

Multispecies models to address trade-offs in Tier-2 are in development, but progress has been more limited. A simple 3-species model for the Flemish Cap system was originally used for strategic assessment of the prospect of maintaining Maximum Sustainable Yield (MSY) extraction levels for cod, shrimp, and redfish simultaneously. Results indicated that high yields of shrimp were not compatible with high yields of cod and redfish [62,63,84], but the model implementation was not deemed ready for tactical advice. However, this exploration spurred the development of a follow-up model, which is currently been considered for exploring scenarios for the Flemish Cap fisheries [65,81]. Multispecies analyses for the Grand Bank and Newfoundland Shelf are ongoing, including new models and updates of existing ones (e.g. [48]). Research on modelling subcomponents of these systems have already allowed exploring key predator-prey interactions (cod-capelin-seals), and established that productivity in these systems has been, at least since the regime shift in the 1990s, mostly regulated through bottom-up processes [85,86]. In this context, studies of trends among fish functional groups, environmental and anthropogenic drivers of key fish stocks, and trophic interactions [60–65,79–81,87] are starting to provide the support needed to address species interactions issues in the science advice. For example, estimates of diet composition and consumption of redfish by cod in the Flemish Cap have been used to inform the natural mortality parameterization in a 3M redfish stock-assessment model [88].

As the Roadmap develops, single-species models and analysis continue to be the cornerstone of current science advice. Beyond regular stock-assessments, updating the Management Strategy Evaluation framework for Greenland halibut, a benchmark exercise for Flemish Cap cod, and the review of the NAFO Precautionary Approach framework have been priority topics for SC in recent years [75,77,82].

Work towards evaluating fishing impacts on benthic communities started even before development of the Roadmap itself, but once integrated into it, it has become one of its most developed elements. In response to international calls for the protection of VMEs [89], initial ecosystem management steps involved the protection of some seamounts in the NRA in 2006 [90]. Given the tight timelines required by UNGA 61/105 [91] and subsequent resolutions for reporting on progress, a major effort was devoted to develop the science advisory elements needed to identify and develop recommendations for the protection of VMEs. This process started by identifying locations of high concentrations of cold-water corals and sponges [59,92–94] that allowed NAFO to establish the initial coral and sponge protection zones [95]. These areas were refined, a suite of VME-defining taxa and

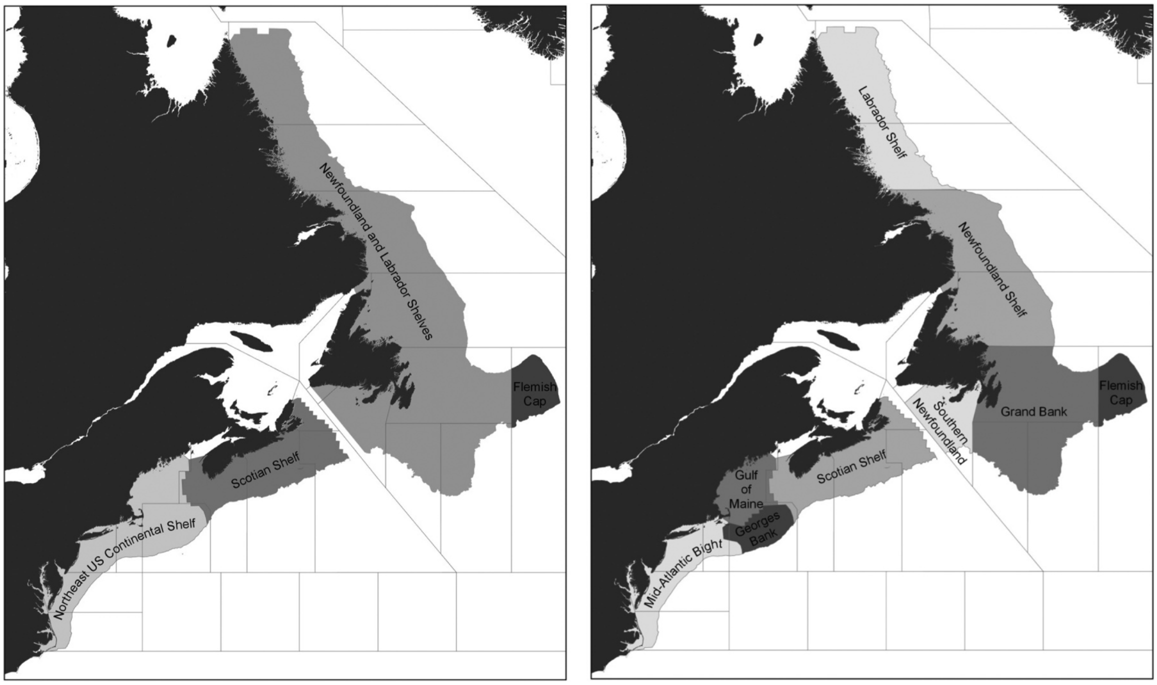

Fig. 4. Bioregions (right) and Ecosystem Production Units (EPUs) (left) currently delineated within the NAFO Convention Area; these spatial units are focused on continental shelf ecosystems where most of the fishing activity takes place.

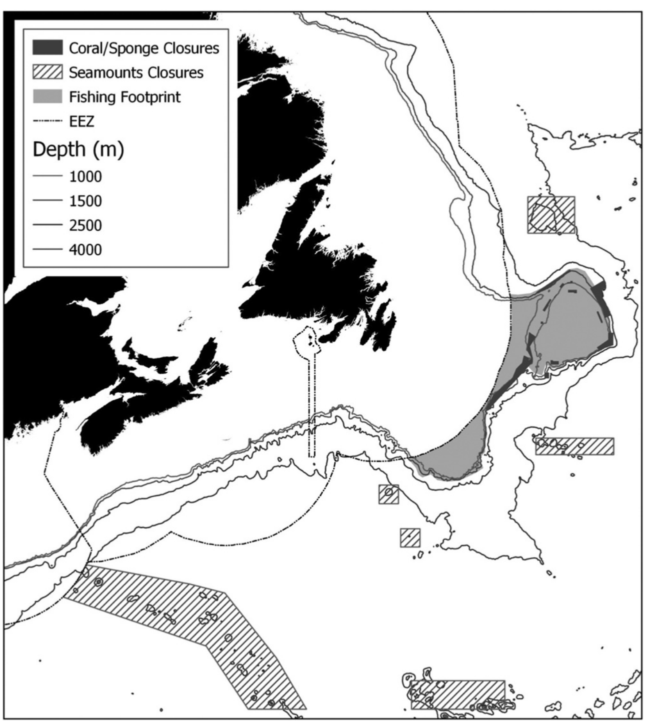

Fig. 5. NAFO seamount closures and coral and sponge protection zones (all closed to bottom fishing activities), with indication of the NAFO fishing footprint, as per NAFO regulations for 2018 [102].

elements compiled, and related management measures implemented (e.g. encounter protocols, move-on-rules) [95–97]. In addition to these measures, NAFO defined its fishing footprint (Fig. 5), and established an exploratory fishing protocol for bottom fishing activities to be carried out outside that footprint [98]. By 2014, a full review on the delineation of VMEs and the adequacy of the existing closures was conducted [64,99], laying the ground work for the first re-assessment of impacts of bottom fishing activities on VMEs in 2016 [100]. This assessment followed the FAO guidelines [46], and considered the distribution of VMEs, the protection granted by the existing closures, and the intensity and location of the fishing effort estimated from Vessel Monitoring System (VMS) records [65,76,99]. This information was used to evaluate the risk of SAIs on core VME classes defined by their dominant VME-taxa (large gorgonians, sponges and sea pens). Conclusions from this assessment indicated that while large gorgonians and sponge VMEs were at a low risk of SAIs, sea pens were at high risk [75], leading to the creation of an additional protection zone for sea pens [101]. This assessment of SAIs on VMEs is now part of the NCEM, and scheduled to be updated every 5 years [102]. Although much of the focus has been on the identification of VMEs, the broader benthic communities have also been characterized and mapped [103] and progress is being made on incorporating benthic ecosystem functioning into impact assessments through mapping and quantifying biological traits.

Although the progress detailed above provides the scientific elements and structure for advice, other important changes in the way NAFO operates were needed to transition toward an EAF framework. In 2007, SC created a working group tasked with providing support for the generation of ecosystem-related scientific advice and start development of an EAF framework for NAFO. The first version of the Roadmap was endorsed by SC in 2010, guiding the subsequent work that led to the Roadmap version described here. By 2013–2014, Roadmap structure and implementation was being discussed by SC and COM, contributing to a process that saw the creation of several joint COM-SC working groups, one of them specifically devoted to the implementation of EAF. At present, the NAFO "ecosystem" management cycle (Fig. 2b) includes a dedicated SC working group which provides most of the science input SC uses for generating advice on ecosystem issues, and a joint COM-SC working group where that science advice is examined and discussed from a management and implementation perspective. This joint working group provides feedback to SC on management implications, ways of implementation, and potential concerns associated with EAF deployment, and input to COM on how to consider the ecosystem advice provided within their decision-making process. Although these are not permanent working groups, their existence today provides the formal pathways through which ecosystem-level advice can be incorporated into the advisory and decision-making processes, while providing a dedicated arena where a scientist-managers dialogue on Roadmap development and implementation can take place.

5. Lessons learned, challenges, and the road ahead

The implementation of the Roadmap in NAFO remains a work in progress. The organization has taken important steps forward since the first version of the Roadmap emerged in 2010, but the road ahead remains complex and challenging. Among the lessons learned, some observations potentially useful to other organizations undergoing similar transition processes are:

1. *An institutional vision is good, but a practical and concrete template of how that vision translates into reality is much better*. In many ways, perhaps the single most useful element in the Roadmap is actually its pictorial depiction (Fig. 3). It allows everyone involved in NAFO, both managers and scientists, to identify where their work and contributions fit and feed the EAF process and bounds expectations. It demystifies EAF by clearly showing what its components are, and provides a useful template to evaluate what has been delivered, and what remains to be done.
2. *Science is not the main roadblock for EAF implementation, governance is*. There are many things yet to be understood about ecosystem interactions and dynamics, but many things are. If the current Roadmap design is any indication, available science can be used to inform an EAF framework, start implementing those elements considered robust enough, and continue working on those that are not. In this context, a key piece for implementation is how existing governance structures can be adapted to deliver EAF. In the case of NAFO, the ability of revising its NCEM on a yearly basis gives the organization a unique tool for rapid and effective updates of its own governance structure. However, a balance has to be struck between overly frequent updates, and too laggard an approach. Perceptions that an issue will never be fully addressed to everyone's satisfaction causes delays in addressing it, and may hinder implementation of time-sensitive measures when key advances in understanding are achieved.
3. *Keeping the science advice at arm's length of the management process is important, but bringing scientists and managers together is the most effective way of implementing an EAF framework*. Scientific analyses and science advice have to be fully independent of management; that is the only way to ensure that the evidence used to support management decisions can be trusted by all parties regardless of sectoral interests and positions. However, implementing EAF requires a learning and communication process, so that managers can fully understand the concepts, assumptions, and limitations of the models and analyses supporting EAF implementation. In the case of NAFO, the creation of joint COM-SC working groups has promoted a more fluid and open dialog between managers and scientists, where the technical ideas and concepts are confronted with the practical aspects and limitations of the decision-making process.
4. *Natural sciences are foundational for EAF, but are not enough*. The Roadmap uses current ecological understanding to create a practical framework that can support evidence-based decision making for managing fisheries in an ecosystem context. However, an EAF framework is not just about sustainability from an ecological perspective, it must also incorporate the human dimension. Since decision making in NAFO is akin to a diplomatic negotiation, official positions are based on internal discussions within each CP delegation. Socio-economic and cultural considerations most certainly factor in defining these official positions, but how this is done within each delegation remains confidential. Although the inclusion of human dimensions must not be cast aside, it is the most complex aspect of EAF implementation, and pushing for its explicit treatment early in the EAF development can delay uptake of EAF as a whole if the organization is not ready for that conversation.
5. *Short and highly connected organizational structures may be more effective*. NAFO has a well-defined hierarchical structure but because the organization is "short" the transmission of information to senior managers can be very rapid and direct, and many times the "translation" of the science to managers and stakeholders within each CP delegation is done by the scientists directly involved in the analyses or the peer-review process of those analyses. This can lead to the development of management options and research objectives that are practical and realistic from the managers' perspective.
6. *A bird in the hand is better than two in the bush; be pragmatic*. Succeeding at implementing EAF in a single sweeping move is unlikely, but management issues will arise that may be more effectively addressed using an ecosystem perspective. The protection of VMEs is a good example from the NAFO experience. This "low hanging fruit" helped garner momentum to start a path towards implementing EAF approaches, but care must be taken to avoid falling into the trap of believing that addressing only these issues ***is*** the EAF implementation. However, it is also important to recognize that most jurisdictions around the world are still struggling to move from single-species to EAF frameworks, so aiming at deploying highly complex and interconnected ecosystem management frameworks is likely to be unrealistic in many cases.
7. *Implementing EAF is a marathon, not a sprint*. Implementation of EAF requires changing, updating and integration of existing instruments and creating new ones, from simple regulations, to policies, all the way to law in some instances. Even with steady commitment from governments and stakeholders, support may waver or change over time (e.g. changing political priorities). A related element that often hinders EAF implementation is the high turnover rate of the people participating in the process, especially among managers. A good practice to keep organizations on course is the implementation of periodic performance reviews (e.g. [104]) to keep long-term objectives in focus.
8. *For EAF development, effective communication is essential*. The critical role of effective communication in developing an EAF framework cannot be overstated. Implementation of EAF is breaking new grounds, with many unfamiliar concepts being developed and used to describe the framework, its components, and the theoretical rationale that supports them. Scientists may be familiar with many of them, managers less so, and for many stakeholders these can be completely new. Based on the Roadmap experience, multiple iterations are required before a new idea or concept is properly understood, accepted, and ready for implementation.

The lessons learned summarized here are consistent and complementary to other analyses reviewing processes aimed at implementing ecosystem approaches [105–107]. Furthermore, when compared with the Fisheries Ecosystem Plan (FEP) Loop, and the key considerations for the creation and implementation of FEPs identified by the Lenfest Ecosystem Task Force [9], the Roadmap possesses many of the features associated with next generation FEPs. It responds to NAFO objective and vision, implements a loop where both ecosystem trends and performance of management actions can be tracked, and builds upon existing science tools and processes, while the NAFO governance structure through the composition of CP official delegations provides an avenue for stakeholder engagement. These observations indicate that the path to implementation of EAF on the high seas by RFMOs would have more in common with ecosystem approaches within EEZs, than ways they may differ. However, some of the emerging differences are important.

Socio-economic and cultural considerations and stakeholder participation are core elements of ecosystem approaches, but these issues are seldom openly discussed in NAFO. Decision-making is based on consensus, and if consensus cannot be reached, a 75% majority vote is required to carry a decision forward, with each CP casting a single vote. CP official positions are based on a multiplicity of factors (e.g. science advice, CPs domestic and international policies, priority issues, bilateral negotiations with other CPs, discussions within the CP delegation). Since stakeholder representatives are members of the official delegations to COM, their input on socio-economic and cultural impacts is an integral element of the internal discussion of a delegation that shapes the final position a CP takes around the COM table. This provides an existing and proven mechanism to incorporate aspects of socio-economic and cultural considerations within the decision-making process, but does not promote transparency on how these issues factor into the final official position. Furthermore, each CP can have completely different ways of valuing these aspects. Without a more formal and transparent process that addresses socio-economic and cultural considerations, quantitative trade-off analyses would be restricted to biological aspects, which could ensure ecological sustainability, but may fall short on socio-economic and cultural sustainability for some CPs.

Explicitly including human dimensions into formal advice would require openly stated socio-economic and cultural objectives, and drawing these objectives requires integrating multiple national and international objectives driven by both CPs domestic policies and international agreements. CPs would need to not just openly share socio-economic and cultural data, but most critically, agree on the way these data should be integrated to provide a balanced representation of the value and impact of alternative management scenarios for each one of them. The conversation on EAF among NAFO CPs has yet to reach this level of development, but as the organization moves into tackling these issues, some useful insights could be taken from ongoing work in other organizations (e.g. [108]).

One important step in moving this conversation forwards would be the development of explicit strategic and operational ecosystem objectives, even if these only consider ecological aspects in their initial iterations. The Roadmap is geared to assess and provide advice on alternative exploitation portfolios for a given ecosystem unit, but these alternative management scenarios need to respond to specific ecosystem objectives. The NAFO convention provides managers with a starting point for this process, but setting operational objectives requires unpacking the NAFO convention objective and vision into concrete and actionable statements. Only with operational ecosystem objectives that recognize the importance of species interactions in the face of changing environments will it be possible to meaningfully inform evaluation of trade-offs that can support "*economic and social benefits deriving from the sustainable use of fishery resources*" and "*promote the long term conservation*".

Traditionally, managers have assessed risk by focusing on statistical rather than structural uncertainty associated with short-term (1–3 yrs) forecasts at the single stock level. However, making decisions in an ecosystem context requires managers to understand the consequences of a changing ecosystem state on the productivity of exploited stocks, including the robustness (i.e. improved accuracy) and uncertainty (i.e. decrease in perceived precision) associated with incorporating ecosystem information. This has implications for short-term forecasts, but most importantly, it highlights the potential impact of varying ecosystem conditions in achieving long-term goals. Managers need to understand how much the activities they have control over can actually have a measurable effect on the state of the ecosystem (or some of its components), and/or if that state is also significantly driven by factors beyond their ability to manage (e.g. climate/environmental forcing, trophic interactions). This represents a fundamental shift in how management actions have to be conceptualized, from actively managing human activities to achieve a specific state, to adapting human activities to improve the likelihood of a specific state, which implies recognizing that management actions, by themselves, may not be sufficient to achieve an objective but can contribute towards it. Equally important is developing the ability to distinguish between objectives that are achievable by management actions alone, and those that are not. Continued dialogue between scientists, managers and stakeholders is essential to devise ecosystem-level objectives and the shift in management perspective that comes with them.

Achieving EAF also requires integration with coastal states. Many of the stocks under NAFO management are straddling stocks, and effective management at the scale of the ecosystem units identified in the Roadmap would require a compatible approach between coastal states and NAFO. Although the Roadmap is generally consistent with the ideas being explored in coastal states (e.g. [1,13,109–112]), a higher level of integration and coordination would be required for the Roadmap to be fully effective. This is particularly relevant for areas like the Newfoundland Shelf and the Grand Bank, where important fisheries are managed by either Fisheries and Oceans Canada (DFO) (e.g. snow crab, northern shrimp) or NAFO (Table 1). Although the ecological analyses required are, for the most part, already being done in an integrated way (e.g. [60,62–65,113]), there is still significant work to be done to develop practical and effective common grounds on the fisheries management side.

After 10 years of continued work, there is tangible evidence that NAFO has begun to move from traditional single-species towards an ecosystem approach to fisheries, but this evolution is far from complete. The Roadmap is providing both the guiding principles for this transition, and a template against which progress can be measured. This effort is certainly positioning NAFO among the leading RFMO/As in the world with regards to the development and implementation of EAF, but with that leadership comes the responsibility of seeing this process through successfully. The real test will be if NAFO can respond to ecosystem changes with rapid and effective management actions. The world is watching.

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Declarations of interest

None.

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