Vol. 617: 341–364, 2019
https://doi.org/10.3354/meps12972

MARINE ECOLOGY PROGRESS SERIES
Mar Ecol Prog Ser

Published May 29

Contribution to the Theme Section 'Drivers of dynamics of small pelagic fish resources: biology, management and human factors'

Value- and ecosystem-based management approach: the Pacific herring fishery conflict

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ABSTRACT: An innovative value- and ecosystem-based management approach (VEBMA) is introduced that aims to expose policy tradeoffs, resolve resource conflicts, and foster ethical governance. VEBMA is applied to the Pacific herring *Clupea pallasii* fishery in British Columbia, Canada, which is mired in conflict between local and indigenous communities and the fishing industry over the management of herring, a forage fish with significant ecological, socioeconomic, and cultural value. VEBMA integrates an ecosystem-based approach (ecological modelling) with a value-based approach (practical ethics) to examine the ecological viability, socioeconomic feasibility, and societal desirability of alternative fishery management scenarios. In the socioecosystem-based approach, we applied the Management Strategy Evaluation module within the Ecopath with Ecosim modelling framework to explore scenarios with harvest-control rules specified by various herring fishing mortalities and biomass cutoff thresholds. In the value-based approach, Haida Gwaii community and herring industry participants ranked a set of values and selected preferred scenarios and cutoff thresholds to open the fishery. The modelled ecological and socioeconomic impacts and risks and stakeholder preferences of the scenarios are synthesized in a deliberation and decision-support tool, the VEBMA science-policy table. VEBMA facilitates inclusive, transparent, and accountable decision-making among diverse stakeholders, such as local communities, industries, scientists, managers, and policy-makers. It promotes ethical governance in pluralistic societies via compromise, rather than consensus solutions to resolve 'wicked' problems at the science-policy interface.

KEY WORDS: Ecosystem-based management · Values · Policy tradeoffs · Ethical governance · Resource conflicts · Wicked problems · Science-policy interface · Decision-support tools · Management strategy evaluation · Lenfest recommendations · Forage fish

1. INTRODUCTION

1.1. Fishery policy is 'wicked'

Fishery policy problems are 'wicked' (Rittel & Webber 1973, Jentoft & Chuenpagdee 2009, Weber et al. 2017), characterized by a plurality of values that defy definitive descriptions or unique solutions. As a consequence, fishery conflicts (Charles 1992) often arise when diverse values, interests, and world-views clash over who owns or controls the fishery resources and how they should be managed and allocated. Fisheries science focuses on single-species or ecosystem-based (albeit seldom implemented) approaches to management and the ecological and economic implications of fishery policy, and only seldom considers

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this social context when recommending management strategies or policy options. However, value conflicts can prevent uptake of scientific advice at the science–policy interface, distorting policy outcomes. The political influence that stakeholder interests can exert on decision-making is evident in Japan's 'scientific whaling' (Clapham 2015) and in the European Union's total allowable catches, which, in the period 1987–2011, averaged 33% higher than the scientific recommendations (O'Leary et al. 2011). Making transparent the diverse (e.g. ecological, socioeconomic, and cultural) values and impacts associated with different fishery policies and management scenarios may foster dialogue among stakeholders and aid decision-makers in resolving policy tradeoffs and resource conflicts. Ultimately, recognizing the wicked nature of fishery policy problems can lead to more ethical governance (Lam & Pauly 2010, Lam & Pitcher 2012). Ethical governance is participatory, deliberative, transparent, and accountable decision-making designed to synthesize diverse sources of information and reconcile a plurality of values among stakeholders (Lam 2016a). It thus encompasses responsible (Sissenwine & Mace 2003), ecosystem-based (Berkes 2012), and good (Lockwood et al. 2010) governance.

To tackle such wicked fishery policy problems, we developed a value- and ecosystem-based management approach (VEBMA), with trans-disciplinary research (Johnson et al. 2019) that merges theory and methods from ecology, oceanography, philosophy, psychology, and art. We applied the VEBMA methodology to the Pacific herring *Clupea pallasii* fishery in British Columbia, Canada, to bring out critical aspects of the conflict between the herring industry and local communities. VEBMA combines ecosystem modelling with participatory value-based research to inform policy decisions by making explicit both the plurality of values underlying the conflict and the ecological and societal consequences of alternative fishery management scenarios. Ecosystem modelling was performed to assess the ecological impacts and risks of alternative management scenarios, such as how to manage herring populations vis-à-vis their predators (including commercial fishes and charismatic megafauna) and planktonic prey. Participatory research was conducted to reveal the diverse values at stake, perspectives, and scenario preferences among members of the herring industry and a largely indigenous local community. VEBMA's integrated value- and ecosystem-based management approach to good governance culminates in a deliberation and decision-support tool that exposes policy tradeoffs. The resulting science-policy table allows policy-makers and civil society to transparently weigh the consequences of alternative management scenarios and to resolve resource conflicts.

1.2. Ecosystem-based management of forage fish

Forage fish, such as herring, sardines, and anchovies (Clupeiformes), exhibit complex ecological and population dynamics that complicate their fishery management and policies (Surma et al. 2018b, Siple et al. 2019). These small pelagic fish play a pivotal role within marine food webs, notably in temperate and upwelling ecosystems, as trophic nodes linking larger vertebrate consumers with smaller planktonic invertebrates (Smith et al. 2011, Pikitch et al. 2012, 2014, Engelhard et al. 2014, Surma et al. 2018a,b). Trophic interactions between forage fish and their predators, i.e. carnivorous fish, marine mammals, and seabirds (Engelhard et al. 2014, Essington & Munch 2014) may be governed by bottom-up (Cury et al. 2011, Hannesson 2013, Sydeman et al. 2017) or top-down (Houle et al. 2013, Surma & Pitcher 2015, Moran et al. 2018) control. Forage fish population dynamics are characterized by an *r*-selected life history strategy: i.e. high population growth rates, *r*, fecundities, and natural mortalities; early maturation; and asymptotic stock-recruitment curves that rise steeply near the origin (Adams 1980, King & McFarlane 2003, Pikitch et al. 2014). Forage fish schooling behaviour leads to enhanced vulnerability to fishing, which promotes range collapses at low abundance (Pitcher 1995, 2001). Fishing and climatic drivers may exacerbate these issues to cause high-amplitude recruitment fluctuations (Pikitch et al. 2014, McClatchie et al. 2017), which in turn can lead to stock collapses (Hannesson 2013, Pinsky & Byler 2015, Essington et al. 2015). The Lenfest Forage Fish Task Force has called for precautionary ecosystem-based fisheries management (EBFM) of forage fish (Pikitch et al. 2012, 2014), owing to their vulnerability to fishing and their importance to fished, charismatic, and protected predators; this, however, has not been without debate (Walters et al. 2016, Hilborn et al. 2017, Pikitch et al. 2018).

EBFM attempts to preserve the structure and function of the ecosystem or food web, i.e. the target fish species, their prey and predators, and protected species that encompass the entire resource system (Link 2002, 2010, Pikitch et al. 2004, Marasco et al. 2007, Patrick & Link 2015). This is broader than the ecosystem approach to fisheries (EAF), which considers only the target species or resource and its drivers (Garcia et al. 2003, Garcia & Cochrane 2005). By explicitly incorporating forage fish and their fisheries into entire food webs, ecosystem modelling can systematically compare the ecosystem impacts of alternative management scenarios (Walters et al. 2005, Pikitch et al. 2012), potential precautionary reference points (Smith et al. 2011, Pikitch et al. 2012, 2014), and EBFM approaches (Plagányi 2007, Engelhard et al. 2014, Essington & Munch 2014). To protect the ecosystem-provisioning role of forage fish, it has been recommended (1) to leave at least one third of forage fish biomass for seabirds (Cury et al. 2011); (2) to reduce forage fish fishing mortality rates to ~50% of natural mortality rates, i.e. to ~50% of conventional fishing mortality rates aimed at maximum sustainable yield (MSY; Smith et al. 2011, Pikitch et al. 2012); and (3) to increase minimum biomass cutoff thresholds for opening the commercial fisheries to 40% of the estimated unfished biomass, with recommendations tailored to the information available (Lenfest intermediate information tier; Pikitch et al. 2012, 2014).

Ecosystem-based management (EBM) of marine resources (Browman & Stergiou 2004, 2005) considers the entire integrated ecosystem, including humans (McLeod & Leslie 2009). While conceptually appealing (Grumbine 1994, Larkin 1996), both EBM and EBFM suffer from high system complexity, uncertainty, and competing interests and goals (Pikitch et al. 2004). This creates scientific and implementation challenges, both in policy and practice (Ruckelshaus et al. 2008). Managing multi-species interactions with multiple human agencies, objectives, and stakeholders has led to largely ineffective coordination and collaboration across diverse sectors, activities, and jurisdictions, with ecosystem-based (EB) considerations rarely quantitatively incorporated in setting harvest quotas (Pitcher & Lam 2010). Evaluation of the status of EBFM implementation in the 33 top fishing nations yielded dismal results: no country scored 'good', only 4 were 'acceptable', and 18 had 'fail' grades (Pitcher et al. 2009). Reconciling EBFM policy tradeoffs (Link 2010, Siple et al. 2019), as in Antarctica (Constable 2011) and the Baltic Sea (Möllmann et al. 2014), requires ethical (Lam & Pauly 2010, Lam & Pitcher 2012) governance approaches that weigh diverse values.

1.3. Adding value to ecosystem-based management approaches

Balancing sustainable use and biodiversity conservation in fisheries management requires identifying socially acceptable ecological impacts and risks (Jennings et al. 2014). This becomes clear when one recognizes that '[m]anagement goals are statements of values — certain outcomes are selected over others' (Grumbine 1994, p. 32). Though values orient and motivate human activities (Brosch & Sander 2016a), their explicit articulation in traditional approaches to resource management, including EBFM, is missing. Value-based (VB) approaches are needed to aid decision-makers in resolving policy tradeoffs and resource conflicts. Values are explicitly recognized in wicked problems (Rittel & Webber 1973, Weber et al. 2017), post-normal science approaches to science-policy problems (Funtowicz & Ravetz 1990, 1993), structured decision-making for environmental management choices (Gregory et al. 2012), understanding environmental behaviours and decisions (Dietz 2016), communicating science (Dietz 2013), and the Intergovernmental Platform on Biodiversity and Ecosystem Services (IPBES) human-nature conceptual framework (Díaz et al. 2015, 2018). In structured decision-making, multi-criteria objective measures are evaluated by technical experts to assess the consequences of alternatives, among which stakeholders choose by making value tradeoffs (Gregory 2002, Failing et al. 2013). This approach, however, assumes a clear separation of facts and values, which is rarely the case. Alternatively, value taxonomies (Rabinowicz & Rønnow-Rasmussen 2016), as articulated by the IPBES (Chan et al. 2016, 2018), can focus policy options and clarify the source of conflicts when different kinds of values obscure decision-making. Simply categorizing values, however, does not resolve policy tradeoffs or resource conflicts. VB approaches are needed that systematically identify the plurality of values in differentiated publics and analyze how such values interact to influence individual and policy decisions. An empirical science of values that not only recognizes their dynamic and context-specific nature, but also investigates how values alter the perception and uptake of 'facts' in decision-making processes may help to resolve resource conflicts.

Valuation approaches that research the process of attributing value to something (Brosch & Sander 2016b, Pascual et al. 2017) may provide the often missing context to value-based decisions by relating values to decision-making and action. One emerging valuation framework maps decision values of different choice options in individual 'value landscapes', where different value landscapes reflect different weightings of core values (Brosch & Sander 2016b). European 'value landscapes and isobars' were mapped to detect areas of convergence and conflict as blueprints to promote better dialogue for value-informed governance of science and technology (Kaiser 2012). Applying this practical ethics approach, Bremer et al. (2016) asked Asian stakeholders to rank values, to map value landscapes for aquaculture development scenarios, and to produce sustainability indicators. Values were also ranked in an interactive 'P+sort' method designed to elicit stakeholder values and principles to guide fishery governance in South Korea (Song & Chuenpagdee 2015) and in a Q sort methodology designed to examine how people prioritize outcomes of marine management in Haida Gwaii, Canada (Loring & Hinzman 2018). These VB studies, however, did not investigate the ecological impacts and risks of the management or governance scenarios. VB approaches offer a low-cost heuristic in data-poor or uncertain conditions, but need to be complemented with EB approaches to identify not only desirable, but also sustainable natural resource policy options.

Hence, we present an innovative value- and ecosystem-based management approach (VEBMA) that integrates EB and VB approaches to marine resource management. VEBMA's strengths and weaknesses are examined in the context of a case study, the Pacific herring fishery conflict in western Canada. We conclude with reflections on VEBMA's methodological innovation, its ecological, management, policy, and governance implications for the Pacific herring fishery, and its potential generalizability to resolving resource conflicts and to facilitating ethical governance capable of resolving resource conflicts.

2. MATERIALS AND METHODS

2.1. The context: Pacific herring fishery conflict

VEBMA was developed to help resolve the Pacific herring *Clupea pallasii* fishery conflict between coastal and indigenous communities and the herring industry in British Columbia (BC), Canada (Lam 2015, Levin et al. 2016, Pitcher et al. 2017). Pacific herring have ecological, socioeconomic, and cultural values that are often absent in evaluations of herring fishery policy options. To facilitate ethical governance, VEBMA makes explicit the diverse values, impacts, and risks of alternative herring fishery management scenarios to the marine food web, local herring industry, and coastal and indigenous communities.

National oceans legislation (Canada's Oceans Act 1997, DFO 2002) is guided by the principles of sustainable development, the precautionary approach, and integrated management. Despite this, the federal regulatory body responsible, Fisheries and Oceans Canada (DFO), manages herring using a single-species rather than ecosystem-based approach (Baum & Fuller 2016, DFO 2018, 2019). This management approach largely ignores the critical role of herring in the Northeast Pacific food web, i.e. its ecological value, as a forage fish (Shelton et al. 2014, Surma et al. 2018b) and major energy conduit (Surma et al. 2018a) between zooplankton prey (mainly euphausiids, amphipods, and copepods) and predators (carnivorous fish, marine mammals, and seabirds). Ecosystem simulation modelling suggests that herring depletion would adversely affect not only the commercial herring fishery, but also predator populations, with impacts cascading through the Northeast Pacific or Haida Gwaii marine food web (Surma et al. 2018b).

The BC herring fishery includes commercial roe herring (gillnet and seine), spawn-on-kelp (SOK), and food, bait and other, as well as a traditional food fishery. In the 1950s and 1960s, the BC industrial reduction fishery depleted herring stocks, leading to a province-wide closure from 1967 to 1971 (Pitcher et al. 2017). A lucrative roe herring fishery started in BC in the 1970s in response to the collapse of Hokkaido herring stocks, but declining Japanese export demand (Carlson 2005) has drastically reduced its socioeconomic value. In 2017, the roe herring fishery and its products, herring roe, herring meal, and animal feed, accounted for the largest share of the herring harvest (73 %, 20 400 t; cf. over 500 000 t at its peak in the 1960s), landed value (64 %, \$17.7 million USD), and wholesale value (75 %, \$51.2 million USD). The (non-capture) SOK fishery had the second largest share of herring landed value (24 %), while the food, bait, and other had the second largest herring harvest (26 %) and wholesale value (15 %) (British Columbia Ministry of Agriculture 2019). Ownership of BC herring fishing licenses is highly concentrated, with one vertically integrated corporate entity (a dominant processor) controlling 21 % of gillnet, and 26 % of seine licenses, and harvesting 24 % of the roe herring catch in 2012 (Haas et al. 2016).

Pacific herring also have significant cultural value for BC coastal indigenous communities, notably the Haida (Jones et al. 2017), Heiltsuk (Gauvreau et al. 2017), and Nuu-chah-nulth First Nations (Uu-a-thluk 2018), as well as the Tlingit in Southeast Alaska (Thornton 2015). Herring eggs or roe laid on organic substrates, such as kelp fronds (SOK) or Western hemlock *Tsuga heterophylla* branches, constitute traditional foods and trade goods (Thornton et al. 2010, Moss 2016). In Canada, First Nations have an Aboriginal right to fish for food, social, and ceremonial purposes, which takes priority, after conserva-

Fig. 1. Case study area: Haida Gwaii ('Islands of the People'), an archipelago in northern British Columbia, Canada, and ancestral homeland of the (indigenous) Haida, showing its surrounding waters, a highly productive and diverse marine ecosystem in the Northeast Pacific

tion, over other uses (Constitution Act, 1982; Canada. Department of Justice 2013). In the landmark *Regina v. Gladstone* case (Harris 2000), the Supreme Court of Canada recognized the Heiltsuk Nation's unextinguished Aboriginal right to a commercial SOK fishery. Amidst this legal context, BC First Nations are seeking to secure their fishing rights and protect their cultural and commercial interests in herring SOK (von der Porten et al. 2016).

In Haida Gwaii, an archipelago in northern BC and ancestral homeland of the Haida (Fig. 1), the commercial roe herring and SOK fisheries have been closed since 2003 and 2005, respectively (DFO 2016a). Despite poor stock status and uncertain forecasts, the Minister of Fisheries and Oceans re-opened the commercial herring fishery in both 2014 and 2015 (Lam 2015, von der Porten et al. 2016, Jones et al. 2017, Pitcher et al. 2017, Raman et al. 2018). Negotiations between the Council of the Haida Nation (CHN) and the industry averted serious conflict in 2014, while in 2015, the CHN won an interlocutory injunction to keep the fishery closed, with the Federal Court judge citing the potential for irreparable harm to herring and to Haida Aboriginal rights (Jones et al. 2017, Raman et al. 2018). Since 2016, under a new federal government, the commercial herring fishery has remained closed in Haida Gwaii.

2.2. Novel methodology: value- and ecosystem-based management approach (VEBMA)

VEBMA was conceptualized by M. E. Lam by synthesizing theory and methods from ecology merging theory and methods from ecology, oceanography, philosophy, psychology, and art. VEBMA combines EB and VB approaches to resource management to explicate the ecological and societal values underlying resource conflicts and the impacts and risks of policy tradeoffs. Ecosystem modelling, the EB component, explores interactions of herring populations vis-à-vis their prey and predators to assess the ecological impacts and risks of alternative management scenarios. Practical ethics, the VB component, reveals diverse stakeholder values, knowledge, and preferences. VEBMA's integrated approach is both descriptive and evaluative: it culminates in the VEBMA science-policy table, a deliberation and decision-support tool that makes transparent the ecological and societal implications of alternative fishery policy choices. This prepares the ground for normative judgments in ethical decision-making and governance.

2.2.1. Ecosystem-based (EB) approach: ecosystem modelling

Ecopath with Ecosim (EwE) framework. VEBMA's EB component relies on ecosystem simulation modelling, specifically the Ecopath with Ecosim (EwE) framework (Christensen & Walters 2004), to describe the ecological and socioeconomic impacts and risks of alternative fishery management scenarios. Ecopath creates, based on the principle of mass balance, a static food web model parameterized with ecophysiological parameters and diet data. This ecosystem 'snapshot' is used to calculate ecological metrics and serves as the initial state for dynamic simulations in Ecosim. Ecosystem dynamics can be driven by time series of primary production and are determined by a predator-prey foraging arena algorithm, where vulnerability parameters are fitted to empirical time series survey data, such as biomasses and catches. EwE is the most widely used modelling tool for ecosystem approaches to fisheries management, as it can identify and quantify major energy flows in an ecosystem, describe the ecosystem resources and their interactions with each other and unfished species, evaluate ecosystem effects of fishing or environmental changes, and explore management policy options by incorporating ecological, economic, and social dimensions of fisheries (Plagányi 2007). Strengths of EwE are its structured parameterization framework, conceptual realism, and predator-prey interaction terms, while its weaknesses arise primarily from user misuse (Plagányi 2007). To address this issue and to better inform management, guidelines were identified for building and balancing Ecopath models, fitting Ecosim models to time series data, using EwE models, and evaluating output uncertainties (Heymans et al. 2016).

The EwE model of the Haida Gwaii marine food web and fisheries (details in Kumar et al. 2016) was updated from Ainsworth et al. (2008) and uses over 50 yr of time series survey data from this location. Of the 56 functional groups in the EwE model, 4 are forage species: adult and juvenile Pacific herring, eulachon *Thaleichthys pacificus*, an aggregate of several smaller fish species (e.g. Pacific sandlance *Ammodytes hexapterus*, capelin *Mallotus villosus*, and small smelts), and krill (mainly *Euphausia pacifica* and *Thysanoessa* spp.). Since the diet of Pacific herring shifts with ontogeny (Beattie 1999, Pakhomov et al. 2017), a multi-stanza approach was used to represent herring by 2 age classes, namely, adults and juveniles, feeding predominantly on euphausiids and copepods, respectively, linked by a Beverton-Holt stock-recruitment relationship. Changes in functional group biomasses were simulated to investigate Northeast Pacific food web structure and function, as well as top-down (predators and fishing pressure) and bottom-up (primary production) forcing on Pacific herring (Surma et al. 2018b). The importance of herring to the food web was investigated by calculating the Supportive Role to Fishery ecosystems (SURF) index (Plagányi & Essington 2014).

EwE Management Strategy Evaluation (MSE) or closed-loop simulations. As an innovation, to account rigorously for uncertainties in the policy context of the dynamic ecosystem simulation modelling, T. J. Pitcher determined to use EwE Management Strategy Evaluations (MSEs), rather than simple fishing choices, to compare the ecosystem outcomes of alternative herring fishery scenarios. MSE evaluates the performance of management scenarios (Fulton et al. 2014, Punt et al. 2016) against quantitative metrics relative to target fish stocks and food webs to compare the risks of policy choices (Kell et al. 2016). To account for uncertainty in primary production, each EwE MSE scenario was run for 100 simulated years, with annual phytoplankton biomass driven by a single time series generated by Monte Carlo resampling (Surma & Pitcher 2015) of observed values from 1950 to 2000 (Ainsworth et al. 2008). To replicate BC herring fishery management, annual quotas were set from herring biomasses determined by simulated stock assessments in the MSE module. Stochastic herring stock assessment error was simulated by 100 runs of each EwE MSE scenario, with Monte Carlo resampling of herring biomass estimates from assumed normal distributions (the coefficient of variation was 0.3 for adult herring and 0 for all other groups). Simulated food web effects from stock assessment uncertainty, however, are small relative to primary production uncertainty.

Impacts of the herring fishery management scenarios on herring and the marine food web were investigated for 2 types of harvest-control rules (HCRs): (1) constant target fishing mortality rate, F, and (2) step, with constant F and a biomass cutoff threshold, B_c, below which the herring commercial fishery is closed. B_c is expressed relative to the unfished spawning biomass, B_0. In the EwE simulations, B_0 is estimated from projected herring recovery under an Ecosim scenario of no herring fishing ($F = 0$) run for 1000 yr, whereas DFO estimates B_0 from historical abundances calculated by single-species stock assessment models that do not explicitly account for food-web interactions between herring and its predators and prey (Surma et al. 2017).

Table 1 lists the herring fishery management scenarios modelled within the EB approach using the EwE MSE module (Surma et al. 2018b), namely *No Fishing* ($F = 0$, i.e. no commercial herring fishery); *SOK* ($F = 0.01$, the estimated maximum incidental herring mortality in the commercial SOK fishery); *Lenfest Precaut* ($F = 0.2$, $B_c/B_0 = 70\%$, using an earlier version of the model, but see Surma [2019], and informed by the Lenfest precautionary threshold of 80% for low information, Pikitch et al. [2012, 2014]); *Lenfest* ($F = 0.2$, $B_c/B_0 = 40\%$, informed by the Lenfest recommended threshold of 40% for intermediate information, Pikitch et al. 2012, 2014); *BC* ($F = 0.2$, $B_c/B_0 = 25\%$, i.e. DFO policy[1]); *Open* ($F = 0.2$,

[1]Here, we focus on the DFO policy of $F = 0.2$ and $B_c/B_0 = 25\%$ at the time of the study. DFO also has a precautionary policy of $F = 0.1$, when herring biomass is near the cutoff or there are stakeholder concerns about stock status (see Surma et al. 2018b). After this research was completed, DFO set $B_c/B_0 = 30\%$ (Kronlund et al. 2018)

Table 1. Herring fishery management scenarios in the VEBMA study: quantitative ecosystem-based (EB) scenarios, modelled using the EwE Management Strategy Evaluation (MSE) module, specified with their constant fishing mortality F and step (constant F with biomass cutoff thresholds B_c/B_0) harvest-control rules (HCRs) and MSE labels, and their rough equivalence with the qualitative value-based (VB) scenarios, with their names and focal values

Scenario description	Fishing mortality, F	Biomass cutoff threshold, B_c/B_0 (%)	MSE label	Name	Focal Value
No commercial herring fishery (Baseline)	0	All (Roe, SOK, Food, Bait & Other): 100	*NO FISHING*	*A whale of a time*	Ecological
Only commercial spawn-on-kelp (SOK) fishery	0.01	Roe: 100 SOK: 0	*SOK*	*The fish that get away*	Cultural
No commercial herring fishery (Closure)	0.2	Roe & SOK: 100			
Lenfest precautionary (near Lenfest B_c/B_0 = 80 % for low information)[a]	0.2	Roe & SOK: 75 (VB) and 70 (EB)	*LENFEST PRECAUT*		
Lenfest recommended (near Lenfest B_c/B_0 = 40 % for intermediate information)[a]	0.2	Roe & SOK: 50 (VB) and 40 (EB)	*LENFEST*		
DFO policy in British Columbia (BC)[b]	0.2	Roe & SOK: 25	*BC*	*Hard of herring*	Socioeconomic
BC scenario with no good primary production years	0.2	Roe & SOK: 25	$BC_{0.75}$		
BC scenario with only bad primary production years	0.2	Roe & SOK: 25	$BC_{0.25}$		
Commercial herring fishery always open	0.2	Roe & SOK: 0	*OPEN*		
Commercial roe herring and SOK fisheries managed separately, with distinct HCRs	Unspecified	Unspecified		*The little fish that could*	Plural
Commercial herring fishery managed for maximum sustainable yield (MSY)	0.4	Roe & SOK: 25	*MSY*		

[a]Lenfest Forage Fish Task Force recommendations (Pikitch et al. 2012, 2014)
[b]Since the study was completed, the cutoff threshold has been raised to 30 %

B_c/B_0 = 0 %, i.e. fishery always open); and (single-species) *MSY* (F = 0.4, i.e. estimated F_{MSY} using EwE, B_c/B_0 = 25 %). Table 1 also lists the corresponding qualitative scenarios investigated within the VB approach, described in Section 2.2.2.

Each EwE MSE scenario yielded probability distributions of functional group biomasses and herring catches across the 100 simulation years and 100 runs. Fishery impacts were assessed from the means (i.e. grand means over 100 simulation years of 100 runs) of the biomasses and catch distributions over the entire range (all quartiles) of stochastic inter-annual phytoplankton biomass variability (and herring stock assessment errors). Ecological risks of poor functional group biomasses from climate variability (and herring stock assessment errors) used the lowest quartile biomass changes as proxies. For the *BC* scenario, ecological risks of potential climate shifts were examined by resampling phytoplankton biomasses from only below the third quartile of the historical distribution ($BC_{0.75}$, representing 'no good primary production years') and from only below the lowest quartile ($BC_{0.25}$, representing 'only bad primary production years'). Socioeconomic risks of the scenarios were assessed using simulated commercial herring catches (calculated from herring biomasses) as proxies for profit and probabilities of fishery closure (when herring biomass is below the cutoff threshold) as proxies for stability.

2.2.2. Value-based (VB) approach: practical ethics

Participatory approach. Ecosystem modelling can simulate the ecological impacts and risks of the investigated management scenarios, with their associated uncertainties, but cannot determine which scenarios are most desirable. To tackle such normative policy questions, M. E. Lam and M. Kaiser developed a VB approach incorporating citizen participation (Arnstein 1969) and practical ethics (Kaiser 2006, 2016, Lam 2016b). The VB approach was adapted from an ethical decision-support and participatory governance framework (Kaiser et al. 2007) designed to elicit both 'bottom-up' stakeholder and 'top-down' government and expert inputs (Bremer et al. 2016). Given the political context of the fishery conflict, we initiated our study with the Haida Gwaii community and herring industry outside of Haida Gwaii separately, with research participants identified in consultation with the CHN and the Herring Industry Advisory Board (HIAB), respectively. We used snowball sampling, a non-probability sampling technique, where participants suggested additional participants from among their contacts. Our sample is thus not representative, but rather, indicative of the diverse perspectives among members of the Haida Gwaii community and herring industry.

In April 2015, we held consecutive one-day workshops in Skidegate and Old Massett, Haida Gwaii ($n_{Skidegate}$ = 17; $n_{Old\ Massett}$ = 9), introducing our research project and personnel (Lam 2015, PWIAS 2016, Pitcher et al. 2017). Between September 2015 and March 2016, M. E. Lam conducted in-depth, semi-structured interviews of a cross-section of Haida Gwaii residents: Haida elders, leadership, and youth; commercial fishers and license owners; scientists; resource managers; conservationists; ecotourism operators; educators; journalists; and artists. The 47 Haida Gwaii interviewees (n_{HG}) comprised 30 Haida, 16 non-Haida (1 unspecified); 37 men, 10 women, aged 21 to 91; and 15 commercial fishers, 13 with herring experience (all retired). We presented our results to community participants in April 2016.

In September 2016 M. E. Lam and J. Scott met with 5 HIAB members to engage herring industry participants. From October 2016 to May 2017, J. Scott interviewed 28 herring industry members (n_{HI}) residing outside of Haida Gwaii, mostly in the Lower Mainland surrounding the Vancouver metropolitan area (Scott 2017): 23 fishers (22 roe herring: 13 gillnet, 9 seine; 1 SOK; 19 active; 4 retired) and 5 processors. All industry respondents were male, aged 28 to 78, with 3 indigenous, 23 non-indigenous, and 2 declined to specify. In May 2017, the synthesized VEBMA results were vetted at a HIAB meeting, the multi-stakeholder Integrated Herring Harvest Planning Committee meeting chaired by DFO, and a final herring project meeting of representatives of the Haida and Heiltsuk First Nations and an interdisciplinary scientific team. While focus groups were interviewed separately, our results were discussed with them first separately, and then together.

In both the workshops and interviews, participants prioritized, i.e. ranked and discussed 12 values in a value prioritization or value-ranking exercise designed to map their value landscapes in relation to herring fishery management. Next, they were given background information via PowerPoint presentations on 4 topics: (1) Haida concerns about the herring fishery; (2) the main Lenfest findings; (3) the results of the ecological modelling; and (4) descriptions of 4 herring fishery management scenarios, including their ecological, socioeconomic, and cultural implications. They were then asked to indicate their management scenario and cutoff threshold preferences. Finally, in response to open-ended questions, participants shared their herring-related knowledge and experiences, perspectives on herring management, and reflections on what herring means to them.

As part of our participatory approach, we used images and descriptive scenario names to engage research participants and disseminate our results in public science communication activities (Vogl 2017, Murphy 2019). A. S. J. White, a Haida artist and geologist, associated images from her inventory that were resonant for her with the values and scenarios, explaining her rationale in the original workshops in Haida Gwaii. In the interviews, the artwork was incorporated without explanation in the value-ranking and scenario preference exercises, but we asked participants how the artwork may have influenced them. Similarly, rather than labelling the scenarios with nondescript numbers or letters, M. E. Lam and T. J. Pitcher created names to engage and elicit responses from the participants. We reflect on the potential impact on the results of the images and scenario names in our methodology in the 'Discussion'.

A defining aspect of our participatory VB approach is that we do not use a common value metric, as is done in economics (e.g. price, opportunity cost, or willingness to pay), but rather, we explicate the plurality of values that accompanies differentiated publics in wicked policy (Rittel & Webber 1973) and post-normal science (Funtowicz & Ravetz 1990, 1993) problems. Specifically, our methodology captures individual value-rankings and scenario preferences, which we analyze by examining their median group ranks and distributions, respectively, to suggest how to weight policy choices for society, given heterogeneous individual choices. Thus, our VEBMA methodology recommends compromise, not consensus policy solutions within pluralistic societies and offers an integrated value- and ecosystem-based approach to reconcile tradeoffs and resource conflicts among heterogenous objectives, value priorities, and policy preferences. While stakeholder preferences give a sense of the desirability of policy options, the simulated ecological and socioeconomic impacts and risks give information about their viability and feasibility, respectively. By synthesizing this information in the VEBMA science-policy table, overall sustainability and ethical governance (inclusive, transparent, and accountable decision-making) can be facilitated, while building trust and capacity among diverse stakeholders, including local communities, industry, scientists, managers, and policy-makers.

Value-ranking exercise: mapping value landscapes. The value-ranking exercise consisted of ranking a set of 12 culturally contextualized values: Respect, Bal-

Table 2. The set of 12 values used in the value-ranking exercise, with their names in English and in Haida (italics), as indicated (on the front of the value cards, with images as depicted in Fig. 2), and their descriptions (on the back of the value cards). The literature origins of the values are footnoted

Value	Description
Respect · *Yahguudang* or *Yakguudang*[a]	Respect, for each other and all living things, is rooted in our culture. We take only what we need, we give thanks, and we acknowledge those who behave accordingly. Precautionary approach
Balance ('The world is as sharp as the edge of a knife') · *Giid tll'juus*[a]	Balance is needed in our interactions with the natural world. If we aren't careful in everything we do, we can easily reach a point of no return. Our practices and those of others must be sustainable. Sustainable use
Interconnectedness ('Everything depends on everything else') · *Gina waadluxan gud ad kwaagiida*[a]	This principle is comparable to an integrated approach to management. Integrated management
Reciprocity (Giving and receiving) · *Isda ad*	Reciprocity (giving and receiving) is a respected practice in our *diigii isda*[a] culture, essential in our interactions with each other and the natural world. We continually give thanks to the natural world for the gifts that we receive. Equitable sharing
Seeking wise counsel · *Gina k'aadang.nga gii uu tl' k'anguudang*[a]	Our elders teach us about traditional ways and how to work in harmony. Like the forest, the roots of our people are intertwined. Together we consider new ideas and information in keeping with our culture, values, and laws. Adaptive management/Best information
Responsibility · *Laa guu ga kanhllns*[a]	We accept the responsibility passed on (to us) by our ancestors to manage and care for the sea and land. We will ensure that our heritage is passed on to future generations. Inclusive and participatory
Sanctity[b]	Sanctity is about accepting a sacred or spiritual element in the world
Wellbeing[b,c]	Wellbeing is about a good quality of life, a state characterized by essential features such as health, prosperity, and happiness
Freedom[c]	Freedom is about the ability to make your own choices on how to live your life
Justice[b,c]	Justice is about distributing benefits, risks and costs fairly
Authority[b]	Authority is about respecting social order and the rule of law
Group solidarity[b]	Group solidarity is about the sense of belonging and showing loyalty to a group

[a]Haida ethics and values from extensive deliberations by the Haida Marine Working Group (Jones et al. 2010)
[b]Universal foundations from Moral Foundation Theory (Graham et al. 2013)
[c]Western ethical principles from the Ethical Matrix (Mepham 2000)

ance, Interconnectedness, Reciprocity, Seeking wise counsel, Responsibility, Sanctity, Wellbeing, Freedom, Justice, Authority, and Group solidarity (Table 2). The first 6 values were collated by the Haida Marine Working Group and published as Haida ethics and values, with complementary scientific principles of marine management (Jones et al. 2010). The other 6 values were selected from the (Western) ethical principles in the Ethical Matrix (Mepham 2000) and the 'universal foundations' of Moral Foundations Theory (Graham et al. 2013) originating from evolutionary biology and social psychology. Our value set corresponds to a subset of Schwartz's basic human values (Schwartz 1999, 2016), which has inspired numerous global value assessments. The value set used here was designed not to be definitive, but rather comprehensive enough to spark reflection, dialogue, and examination of value relations among a broad spectrum of participants in the context of the Pacific herring fishery conflict. Our value selection thus reflects more the methodological approach of Rokeach (1973), rather than Schwartz.

Portable value cards were created from 4′ × 6′ index cards for the value-ranking exercise, with images depicting values labelled on the front (Fig. 2) and described on the back (Table 2). Respondents were free to sort the 12 value cards into any configuration, i.e. they could assign the number of rank levels and the number of equivalent values within any level. Instructed to use the textual descriptions on the value cards as a guide only, respondents were prompted to explain what each value meant to them after the ranking exercise. Individual and median communal rankings were computed to map their respective value landscapes.

Preference exercises: fishery management scenarios and biomass cutoff thresholds. In the preference exercises, respondents were asked to select among 4 herring fishery management scenarios (listed in Table 1 and depicted as images in Fig. 3): (1) *A whale of a time*

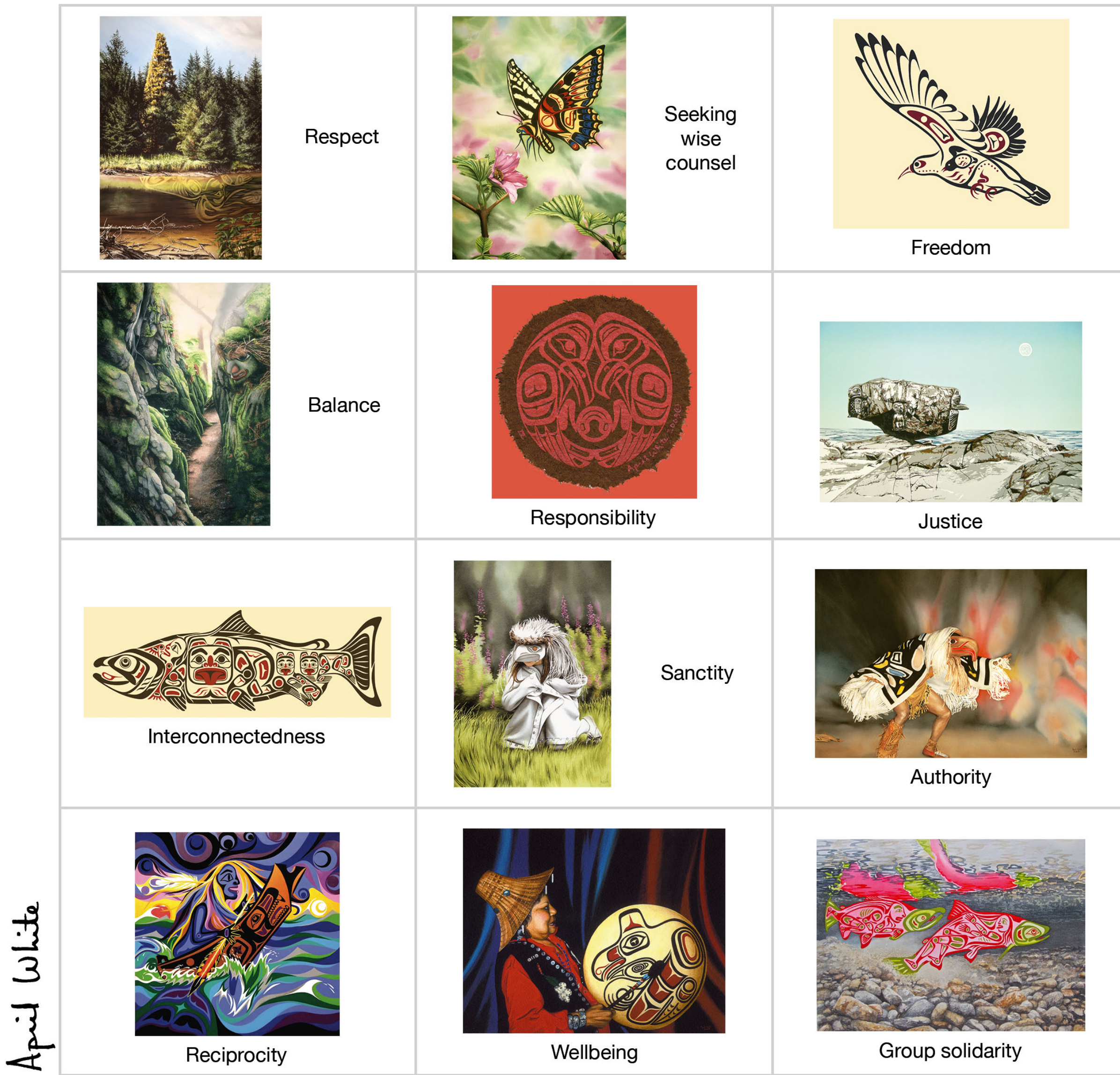


Fig. 2. Set of twelve 4′ × 6′ value cards, with images by Haida artist and geologist April SGaana Jaad White, used in the value-ranking exercise (value names have been shortened for visual clarity): Respect; Balance; Interconnectedness; Reciprocity; Seeking wise counsel; Responsibility; Sanctity; Wellbeing; Freedom; Justice; Authority; and Group solidarity. Table 2 lists the full names on the front and the text descriptions on the back of the value cards. All Fig. 2 images ©April SGaana Jaad White

(no commercial herring fishery); (2) *The fish that get away* (only commercial SOK fishery); (3) *Hard of herring* (DFO policy); and (4) *The little fish that could* (commercial roe herring and SOK fisheries managed separately, with distinct HCRs). These 4 qualitative or narrative scenarios were designed after consultation with the CHN (but unfortunately, not with the HIAB, as the herring industry was engaged later) to highlight particular values of herring: ecological, cultural, socioeconomic, and plural, respectively (see Table 1). Respondents were asked also to select among 5 biomass cutoff thresholds for opening the commercial herring fishery: B_c/B_0 = 100% (fishery closed), 75% and 50% (approximate Lenfest recommendations for low and intermediate information, respectively), 25% (DFO policy), and 0% (fishery always open).

3. RESULTS

3.1. EB approach: ecosystem modelling

Fig. 4 depicts the EwE model of the Haida Gwaii marine food web and fisheries, with 56 functional

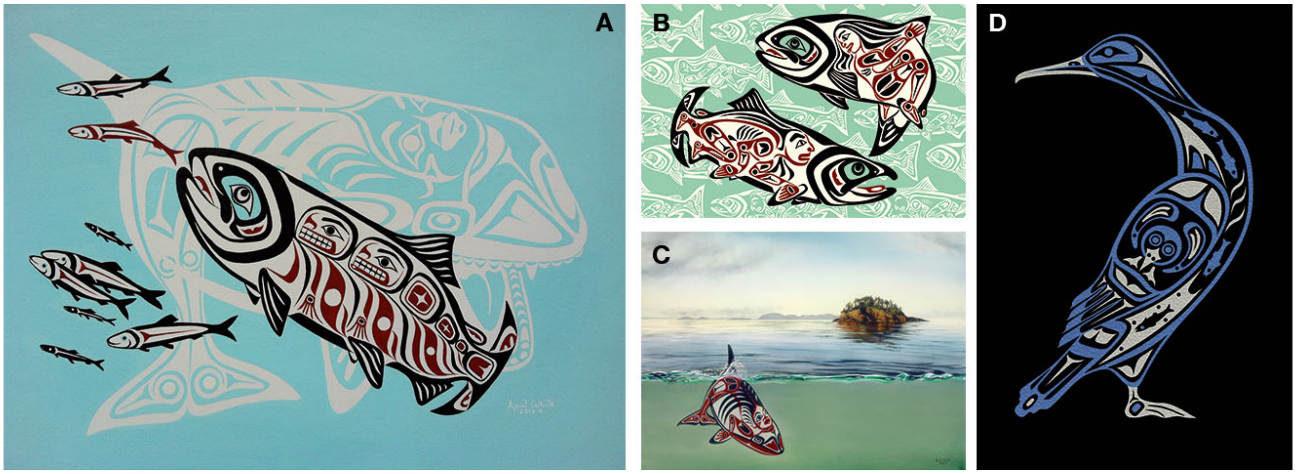


Fig. 3. Images used in the herring fishery management scenario preference exercise (see Table 1 for full scenario descriptions). (A) *A whale of a time* (no commercial herring fishery); (B) *The fish that get away* (only commercial spawn-on-kelp [SOK] fishery); (C) *Hard of herring* (DFO policy); and (D) *The little fish that could* (commercial roe herring and SOK fisheries managed separately, with distinct harvest-control rules). All Fig. 3 images ©April SGaana Jaad White

groups spanning 5 trophic levels, from phytoplankton to orcas, and 21 commercial, recreational, and aboriginal fisheries, including roe herring (both seine and gillnet gear types), SOK, and food and bait. In our Ecopath food web model, the *SURF* index was 0.0006 for herring, slightly below the threshold (0.001) for key forage fish status. However, the biomasses of 15 % of non-herring groups decreased by >60 % in re-

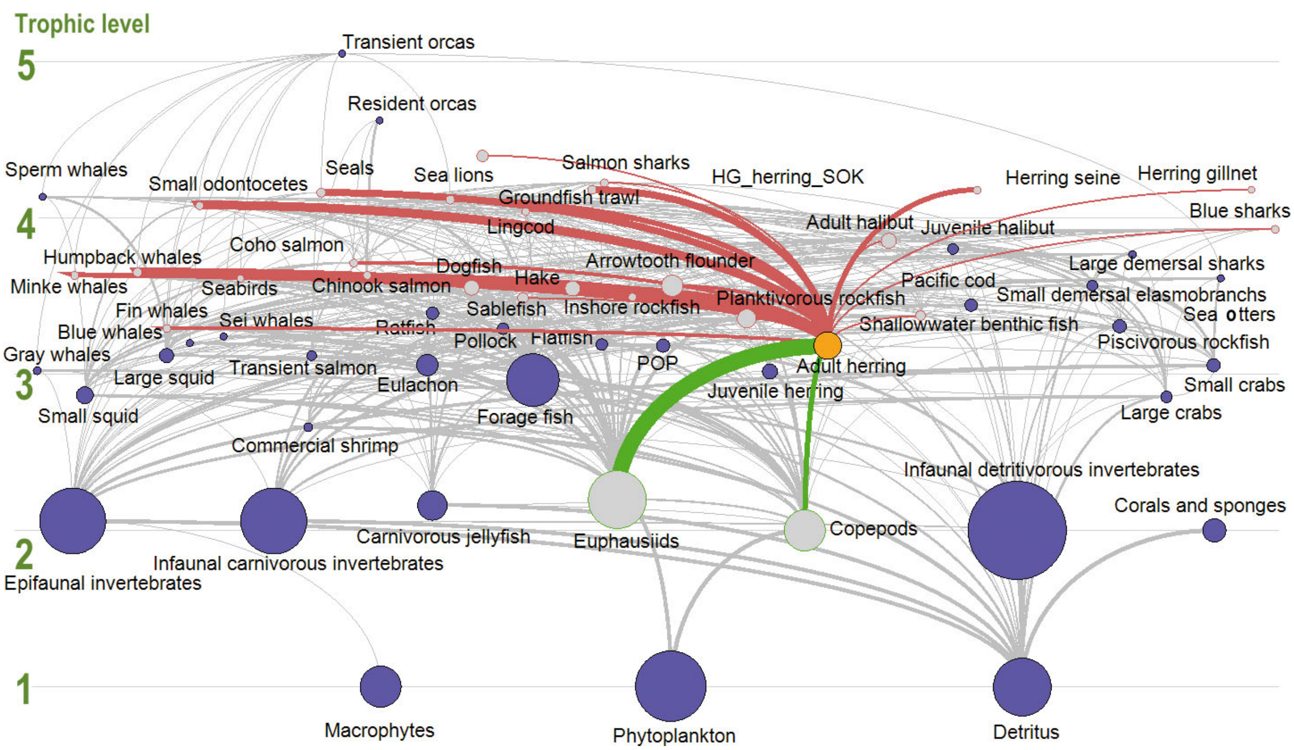


Fig. 4. Haida Gwaii marine food web and fisheries modelled using Ecopath with Ecosim (EwE), with 56 functional groups spanning 5 trophic levels, highlighting adult herring (orange dot) and biomass flows linking them with their prey (green lines) and predators (red lines). Line thickness is proportional to biomass flux (t km^{-2} yr^{-1}). EwE modelling results of the Haida Gwaii (i.e. Northeast Pacific) food web detailed in Kumar et al. (2016) and Surma et al. (2018b). Small odontocetes = dolphins and porpoises; POP = Pacific ocean perch; HG = Haida Gwaii; SOK = spawn-on-kelp

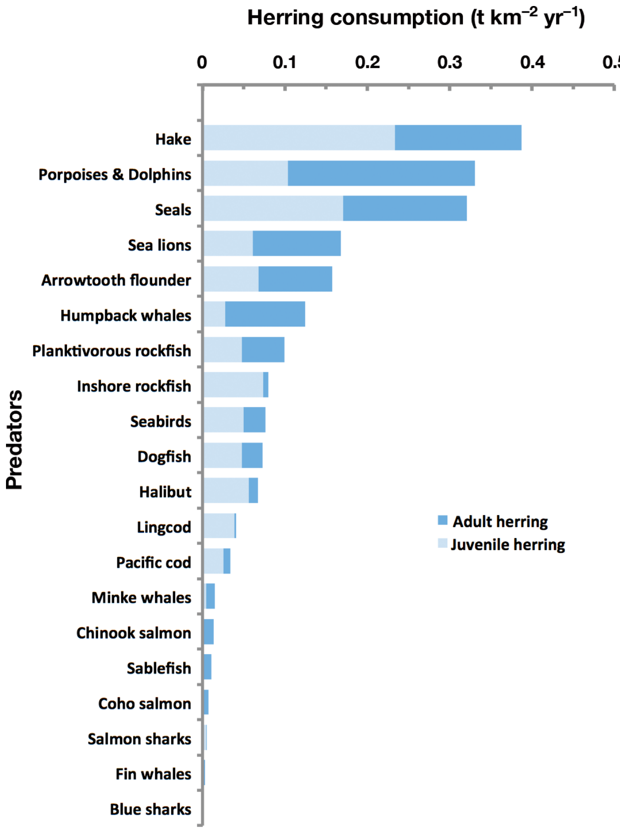


Fig. 5. Consumption of adult and juvenile Pacific herring by its 20 predators in the Haida Gwaii marine food web model

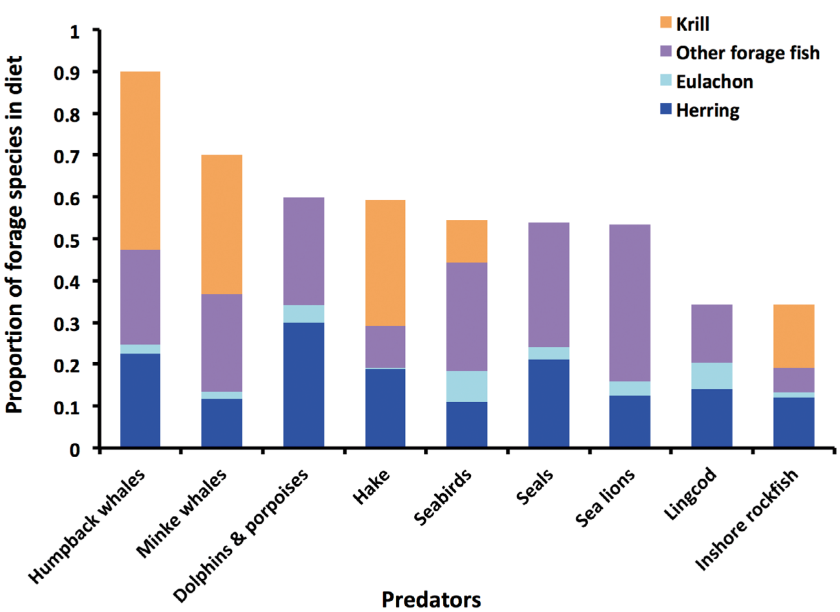


Fig. 6. Dietary dependence of the 9 major herring predators (herring in diet >10%) in the Haida Gwaii marine food web model on forage species: herring, eulachon, other forage fish, and krill

sponse to simulated herring depletion (Surma et al. 2018b), satisfying an alternate requirement for key status (Smith et al. 2011, Plagányi & Essington 2014).

The total consumption of adult and juvenile herring by its 20 predators in the EwE model is approximately 2.0 t km^{-2} yr^{-1} (Fig. 5). The flux of herring through the Haida Gwaii marine ecosystem (Kumar et al. 2016) is about 50% lower than in the North Sea (Dickey-Collas et al. 2010) or Norwegian Sea (Skaret & Pitcher 2016). The total standing biomass of all age classes of herring is approximately 3.5 t km^{-2} and the production is roughly 3 t km^{-2} yr^{-1} (Kumar et al. 2016). Fig. 6 shows the dependence of the 9 major herring predators (herring in diet >10%) on forage species, including herring, eulachon, other forage fish, and krill. Pacific herring constitutes >20% of the modelled diets of dolphins and porpoises (Delphinidae and Phocoenidae), humpback whales *Megaptera novaeangliae*, seals (Phocidae), and Pacific hake *Merluccius productus*, which implies that these predators could be particularly vulnerable to herring biomass changes. Following the Lenfest definitions (Pikitch et al. 2012), humpback whales are extremely dependent on forage species (forage species in diet ≥75%), while 6 herring predators are highly dependent on forage species (forage species in diet ≥50%) in the Haida Gwaii marine food web.

Modelled ecological impacts of the EwE MSE HCR scenarios (Table 1) are represented as percentage mean changes in functional group biomasses (see Fig. 8a) relative to the *NO FISHING* baseline scenario (Fig. 7). Biomass changes were weaker for scenarios with lower herring fishing mortalities (F), higher biomass cutoff thresholds (B_c/B_0), and step HCRs: *NO FISHING* ($F = 0$; $B_c/B_0 = 100\%$) < *SOK* ($F = 0.01$; $B_c/B_0 = 100\%$) < {*LENFEST* < *BC* < *OPEN*} ($F = 0.2$; $B_c/B_0 = 40\% > 25\% > 0\%$) < *MSY* ($F_{MSY} \approx 0.4$; $B_c/B_0 = 25\%$). Regardless of HCR type and B_c, which exhibited weaker effects than F, scenarios with $F < F_{MSY}$ did not disrupt food web structure, yielding biomass changes <20% for all non-herring groups, whereas for $F = F_{MSY}$, ecological impacts were stronger, with more intense biomass changes and more affected groups.

Ecological and socioeconomic risks of the EwE MSE scenarios associated with climate variability and climate shifts also were assessed. Under all HCR scenarios, the lowest quartile

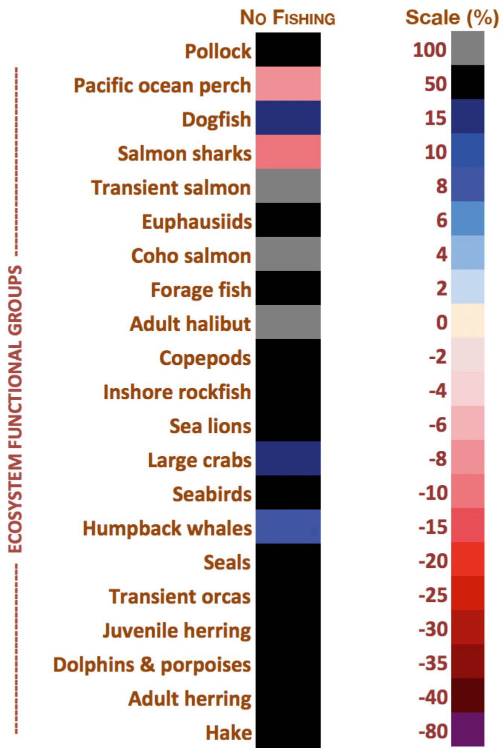


Fig. 7. Herring recovery and ecological impacts, depicted as percentage biomass changes from Ecopath model state for the *No Fishing* baseline scenario: 100-yr MSE simulation with no commercial herring fishery, assuming all other fisheries at current harvest rates, no climate change, and a stable food web

biomass changes, reflecting the 1-in-4 risks of poor biomasses, were strongly negative for most functional groups, suggesting the potential for substantial, adverse ecological impacts within the historical range of climate variability, with and without herring fishing (Fig. 8b). Simulated impacts of the *BC* scenario under climate shifts, $BC_{0.75}$ and $BC_{0.25}$, drastically reduced most functional group biomasses (Fig. 8c). Modelled mean commercial herring catches correlated with high *F* scenarios: *MSY* > *BC* ≈ *Open* > *Lenfest* > *SOK* (Fig. 9a). The probability of herring fishery closure was highest for *Lenfest* (due to high B_c/B_0) > *MSY* (due to high *F*) > *BC*, whereas the fishery is always open for the (constant-*F*) *Open* and *SOK* scenarios (Fig. 9b).

3.2. VB approach: practical ethics

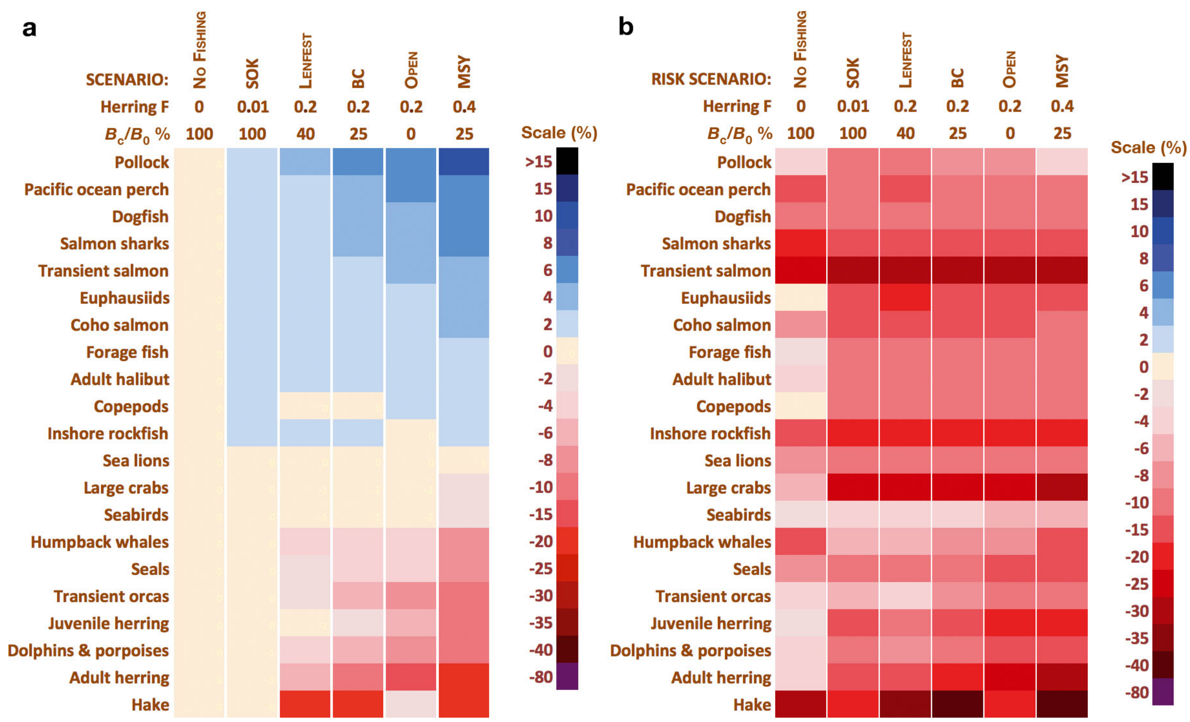
From the value-ranking exercise (Table 2, Fig. 2), communal value landscapes showed no statistical difference between aggregated Haida Gwaii and herring industry results (Fig. 10, n_{HG} = 46, n_{HI} = 25; Wilcoxon test W = 38, df = 12, p > 0.6). For both groups, respect and responsibility had the highest median ranks (ranked first by 59% and 46% of respondents in Haida Gwaii and by 48% and 44% in the herring industry, respectively), while sanctity and authority were the lowest ranked values. Overall, respondents chose a median of 4 rank levels (quartiles 3–10.5) and a mode of 12, with 21% ranking values hierarchically (12 levels), and 8%, equally (1 level).

Haida Gwaii and herring industry respondents, however, had strikingly different preferences (Fig. 11; n_{HG} = 44; n_{HI} = 24; G = 30.2, df = 3; p < 0.0001) among the 4 herring fishery management scenarios (Table 1, Fig. 3). Haida Gwaii respondents stated their scenario preferences, in decreasing order, as *A whale of a time* (no commercial herring fishery), *The fish that get away* (only commercial SOK fishery), and *The little fish that could* (commercial roe herring and SOK fisheries managed separately, with distinct HCRs); none chose *Hard of herring* (DFO policy). In contrast, herring industry respondents stated their scenario preferences, in decreasing order, as *Hard of herring*, *The little fish that could*, and *A whale of a time*, with none preferring *The fish that get away*.

In the cutoff threshold preference exercise, the Haida Gwaii (n_{HG} = 43) and herring industry (n_{HI} = 19) respondents again exhibited strikingly different preferences among the 5 cutoff thresholds for opening the commercial herring fishery (Fig. 12, G = 34.4, df = 4; p < 0.0001). Most Haida Gwaii respondents preferred B_c/B_0 = 100%, corresponding to no commercial herring fishery, followed by the approximate Lenfest recommendations for low and intermediate information, B_c/B_0 = 75% and 50%, respectively; none preferred B_c/B_0 = 25%, the DFO threshold, or B_c/B_0 = 0%, where a commercial herring fishery would always be open. Among the herring industry respondents, the vast majority preferred the current DFO threshold, B_c/B_0 = 25%, followed by B_c/B_0 = 50% and 75%, with none preferring B_c/B_0 = 100% or 0%. Note that in the VB approach, not all research participants completed all exercises, generating variations in the sample sizes.

3.3. VEBMA synthesis: science-policy table

Our VEBMA results are synthesized in a science-policy table (Table 3) designed as a deliberation and decision-support tool. We use a traffic-light colour-coding scheme to indicate the modelled ecological (Fig. 8) and socioeconomic (Fig. 9) impacts and risks and stated scenario (Fig. 11) and threshold (Fig. 12)



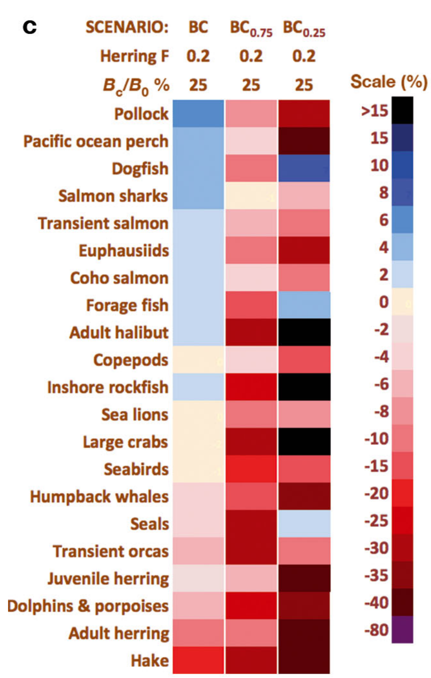


Fig. 8. (a) Modelled ecological impacts of the EwE MSE herring fishery management scenarios for constant fishing mortality, F, and step (constant F with biomass cutoff thresholds, B_c/B_0) harvest-control rules (HCRs; see Table 1). Impacts are expressed as percentage biomass changes, computed as (grand) means over 100 MSE runs (100 yr each) for selected functional groups, relative to the no commercial herring fishery MSE baseline scenario (Fig. 7). Blue (red) denote positive (negative) biomass changes, while the colour intensity reflects the degree of change. The modelled HCR scenarios are, from left to right *No Fishing* ($F = 0$, $B_c/B_0 = 100\%$); *SOK* ($F = 0.01$, $B_c/B_0 = 100\%$); *Lenfest* ($F = 0.2$, $B_c/B_0 = 40\%$); *BC* ($F = 0.2$, $B_c/B_0 = 25\%$); *Open* ($F = 0.2$, $B_c/B_0 = 0\%$); and *MSY* ($F_{MSY} \approx 0.4$; $B_c/B_0 = 25\%$). (b) For the EwE MSE HCR scenarios in (a), ecological risks of low biomasses from climate variability, expressed as first quartile biomass changes, i.e. 1-in-4 risk of low biomasses from climate-driven phytoplankton biomass variability (and herring stock assessment errors). (c) For the *BC* scenario ($F = 0.2$, $B_c/B_0 = 25\%$), ecological risks of climate shift scenarios, showing means of functional group biomasses simulated by resampling phytoplankton biomasses from only below the third quartile of the historical distribution ($BC_{0.75}$, 'no good primary production years') and only below the first quartile ($BC_{0.25}$, 'only bad primary production years')

preferences of the Haida Gwaii community, disaggregated also for Haida and commercial herring fishers, and herring industry respondents outside of Haida Gwaii. The ecological viability of the scenarios, deduced from proxies such as modelled herring biomass and recovery, humpback whale recovery, marine food web structure, and climate variability and shift risks, is compared with their socioeconomic feasibility assessed from their mean herring catches and probability of fishery closure, and societal desirability, as gauged from community and industry stakeholder preferences.

Table 3 also indicates the quality of our VEBMA results. In the EB approach, the 70% threshold results

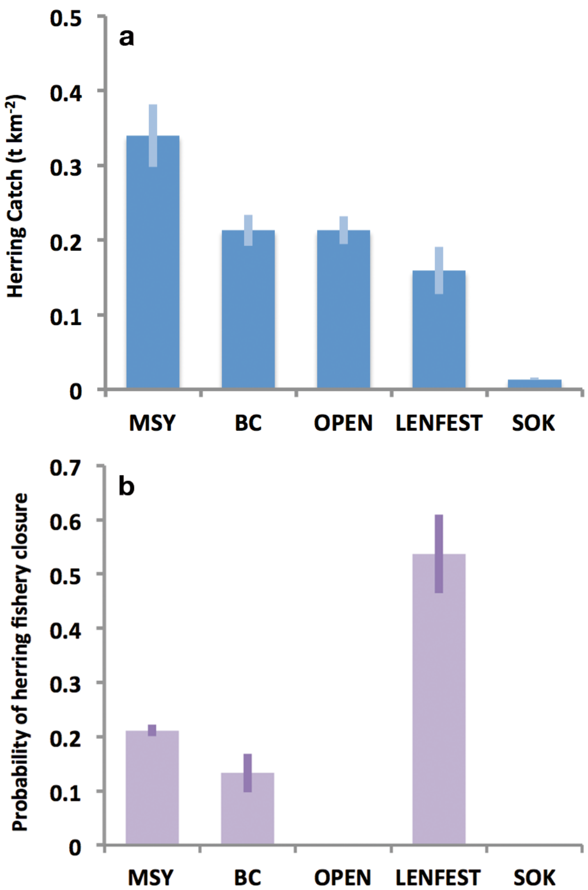


Fig. 9. (a) Mean herring catches for the MSE scenarios, with 95% confidence limits calculated from standard deviations. (b) Probabilities of commercial herring fishery closure for the MSE scenarios (for the *Open* and *SOK* scenarios with constant *F*, the fishery is always open), with 95% confidence limits calculated from quartiles of the herring biomasses

are from an older version of the EwE model, so have medium quality (notably, a newer version of the model yielded comparable results; Surma 2019), while the risks from climate variability and shift were not explicitly modelled for the non-*BC* scenarios, and therefore have lower quality. There are no ecological modelling results for the *Little fish that could* scenario, labelled here as *ROE & SOK*, as the HCRs were not quantitatively specified for this qualitative scenario. In the VB approach, the herring industry results came from fewer respondents, so have medium quality.

4. DISCUSSION

4.1. VEBMA methodological reflections

VEBMA is a highly innovative, transdisciplinary methodology. As such, it needs refinement to our proof-of-concept introduced here. For example, we recognize that some bias may have been introduced by how the values and scenarios were selected, named, and depicted (Tables 1 & 2, Figs. 2 & 3), but given the fishery conflict, their co-construction within a participatory setting with representatives of all stakeholder groups, including affected communities, industry, and fisheries agencies, was not feasible. Despite this, we witnessed clear benefits of the artwork and scenario names in engaging research participants and triggering them with multiple cues. Both cognitive and affective modalities likely elicited in them a wider range of knowledge and experiences to draw upon when reflecting on their subjective values and perspectives on the fishery.

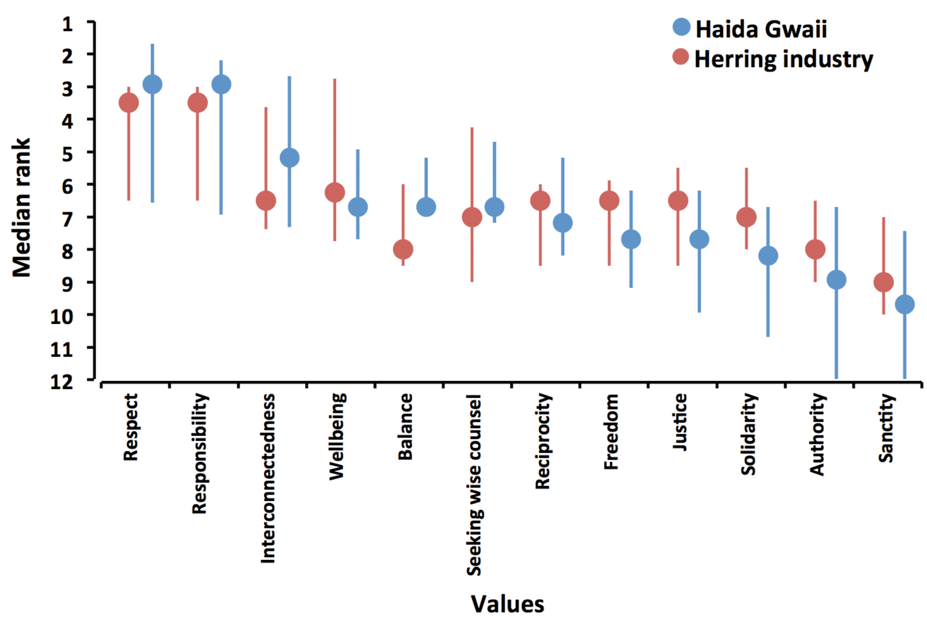


Fig. 10. Median ranks of 12 values (Table 2, Fig. 2) aggregated from value rankings of the Haida Gwaii (n_{HG} = 46) and herring industry (n_{HI} = 25) respondents, showing uncertainty in the communal value landscapes by first quartiles (W = 38, df = 12, p > 0.6)

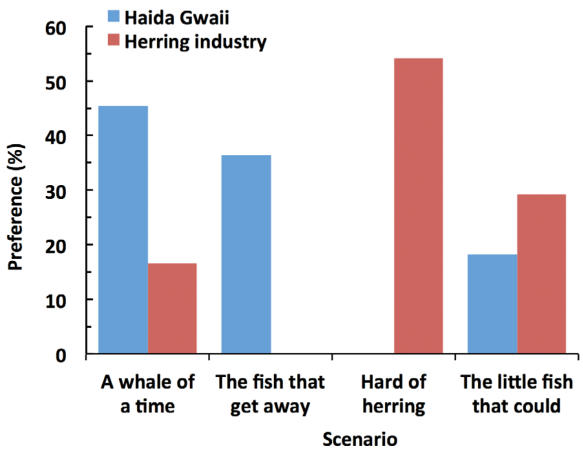


Fig. 11. Stated preferences among 4 herring fishery management scenarios (Table 1, Fig. 3) of Haida Gwaii (n_{HG} = 44) and herring industry (n_{HI} = 24) respondents (G = 30.2, df = 3, p < 0.0001)

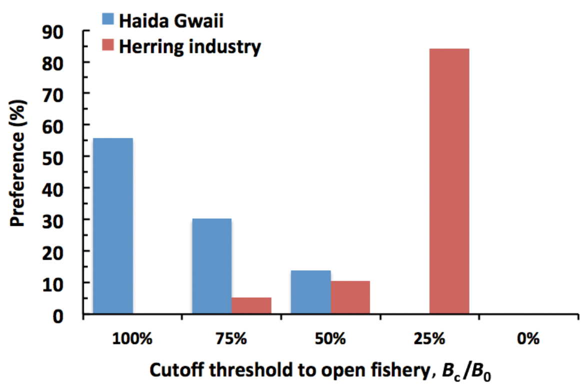


Fig. 12. Stated preferences among 5 cutoff thresholds, B_c, for opening the commercial herring fishery, expressed as percentages of the estimated unfished biomass, B_0, of Haida Gwaii (n_{HG} = 43) and herring industry (n_{HI} = 19) respondents (G = 34.4, df = 4, p < 0.0001)

When asked if the value images influenced their rankings, only 1 respondent, with a background in marketing, said yes, referring to their subliminal effects, whereas another focused exclusively on the images, not the text, in describing the values. Although participant self-reports and researcher observations are no substitute for rigorous controls in methodological design, they do suggest that the images likely did not prime the subjects in their value rankings. On the contrary, we observed the direct benefits of using art in our VEBMA methodology as an engagement and communication tool: participants often reacted positively to the artwork and asked if they could keep the value cards after the interviews, while academic and public audiences of our research presentations appreciated the images and the 'catchy' names.

While we did not rigorously test for potential bias of the scenario names or images, we draw tentative conclusions from observations made in the course of the workshops and interviews. In the Haida Gwaii community workshops, individual participants' responses to the question 'How do you think the Haida Gwaii herring fishery should be managed?', posed at both the beginning and end of the workshop, did not change qualitatively. Individual views were thus stable to possible priming by the scenario names and images, as well as to group discussions. Also, despite consistent methodological materials and protocols, the Haida Gwaii community and herring industry members exhibited common value rankings (Fig. 10), but strikingly distinct scenario preferences (Figs. 11 & 12), suggesting that their scenario choices were biased not by the names or images, but rather by their pre-existing concerns, attitudes, and beliefs about the fishery. Individuals have an identity-protective cognition bias that tends to preserve their cultural identity and beliefs (Kahan et al. 2007, Kahan 2010), which was likely manifest in our research participants.

Scenario design and translation between scenarios and policy choices is not straightforward. Scenarios are 'plausible, challenging, and relevant stories about how the future might unfold, which can be told in both words and numbers;' they help envision future pathways and attempt to account for critical uncertainties (Raskin et al. 2005, p. 35). Translating narrative scenarios into quantitative assessments is complex (Mallampalli et al. 2016), so we designed roughly equivalent EB and VB scenarios (Table 1) and asked research participants to describe their preferences. For the EB scenarios, precise HCRs had to be specified to perform the ecosystem modelling, whereas for the VB scenarios, qualitative descriptions that highlighted the diverse values of herring were paired with quantitative cutoff thresholds that could be modelled. This ambiguity among the quantitative and qualitative scenarios creates space for dialogue and interpretation among diverse perspectives, particularly between 'expert' scientists and 'lay' citizens, by embracing epistemological uncertainties in the scenario designations to equalize participants and engage participation.

Respondents' scenario and threshold preferences can be compared for self-consistency, given their correspondences (Table 1, Figs. 11 & 12), i.e. *A whale of a time* and *The fish that get away* both correspond to B_c/B_0 = 100% for the roe herring fishery, while *Hard of herring* corresponds to B_c/B_0 = 25%. Of the 20 Haida Gwaii respondents who chose *A whale of a time*, 74% chose the corresponding B_c/B_0 = 100%

Table 3. VEBMA science-policy table, a deliberation and decision-support tool, for the Haida Gwaii herring fishery, synthesizing the ecosystem-based (EB) and value-based (VB) results in Figs. 8 & 9 and 11 & 12, respectively. The quantitative and qualitative fishery management scenarios (Table 1) are given the rough equivalence: *No Fishing* corresponds to $F = 0$ and *A whale of a time*; *SOK* to $F = 0.01$ and *The fish that get away*; *Lenfest Precaut* to $F = 0.2$, $B_c/B_0 = 70–75\%$; *Lenfest* to $F = 0.2$, $B_c/B_0 = 40–50\%$; *BC* to $F = 0.2$, $B_c/B_0 = 25\%$ and *Hard of herring*; *Open* to $F = 0.2$, $B_c/B_0 = 0\%$; and *"Roe & SOK"* to *The little fish that could* (quotation marks denote that this scenario could not be modelled, as HCRs were not quantitatively specified). Green indicates low ecological or positive socioeconomic impact or risk (in the EB approach) and a strong stated preference (in the VB approach), red shows high ecological or negative socioeconomic impact or risk (EB) and is not preferred (VB), while olive, grey, and orange colours denote intermediate states, ranging from less to more ecological or better to worse socioeconomic impact or risk (EB) and more to less desirable (VB). The quality of the information sources or knowledge used in the evaluation is indicated by block letters in the upper-right-hand corner of each cell: L, M, and H denote low, medium, and high quality, respectively. The impacts and risks assessed by the EB approach are various proxies of ecosystem or socioeconomic status deduced from simulated biomass changes over the EwE MSE runs: 'Sustainable herring biomass' represents the standing herring biomass; 'Herring recovery' represents the trend in herring biomass; 'Humpback whale recovery' represents the trend in humpback whale biomass; 'Marine food web structure' represents the cumulative impacts on all functional groups; 'Climate variability risks' represent the aggregated functional group biomass response to stochastic inter-annual variance in the primary production; 'Climate shift risks' represent biomass responses to a reduction in the primary production (mean climate) over time; 'Herring catch' represents the mean herring catch modelled in the MSE scenarios; and 'Fishery closure' represents the probability of fishery closure estimated from the modelled herring biomass compared to the cutoff threshold. The stated preferences of the 'Haida Gwaii (HG) community', '(Indigenous) Haida in HG', 'Commercial fishers in HG' and 'Herring industry outside HG' are from the semi-structured interviews conducted within the VB component of the VEBMA study

Information source	SCENARIO	No Fishing	SOK	Lenfest Precaut	Lenfest	BC	Open	"Roe & SOK"
	Fishing mortality, F	0	0.01	0.2	0.2	0.2	0.2	?
	Cutoff threshold, B_c/B_0	100%	100%	70 - 75%	40 - 50%	25%	0%	?
	Focal value	Ecological	Cultural	Ecological	Ecological	Socio-economic	Socio-economic	Plural
EB approach: Impacts and risks	Sustainable herring biomass	H (green)	H (green)	M (green)	H (grey)	H (orange)	H (red)	
	Herring recovery	H (olive)	H (olive)	M (grey)	H (orange)	H (red)	H (red)	
	Humpback whale recovery	H (green)	H (green)	M (green)	H (grey)	H (orange)	H (red)	
	Marine food web structure	H (green)	H (green)	M (olive)	H (grey)	H (orange)	H (red)	
	Climate variability risks	M (olive)	M (olive)	L (grey)	L (orange)	H (red)	H (red)	
	Climate shift risks	M (orange)	M (orange)	L (orange)	L (red)	H (red)	H (red)	
	Herring catch	H (red)	H (red)	M (orange)	M (olive)	M (green)	H (green)	
	Fishery closure	H (red)	H (red)	M (orange)	M (orange)	M (grey)	H (green)	
VB approach: Preferences	Haida Gwaii (HG) community	H (green)	H (olive)	H (olive)	H (grey)	H (red)	H (red)	H (grey)
	(Indigenous) Haida in HG	H (green)	H (green)	H (olive)	H (grey)	H (red)	H (red)	H (grey)
	Commercial fishers in HG	H (green)	H (olive)	H (olive)	H (orange)	H (red)	H (red)	H (grey)
	Herring industry outside HG	M (grey)	M (red)	M (orange)	M (grey)	M (green)	M (red)	M (grey)

($G = 38.8$, df = 1, $p = 0.001$), while of the 13 herring industry respondents who chose *Hard of herring*, all 11 who chose a threshold (85%) selected the corresponding $B_c/B_0 = 25\%$ ($G = 6.9$, df = 1, $p = 0.005$). This shows that stated scenario and threshold preferences are largely self-consistent, which internally validates the methodology.

By using an illustrated, comprehensive, and resonant set of values (Table 2, Fig. 2) in relation to fishery management scenarios, VEBMA engaged diverse participants in meaningful discussions about their values and management preferences. When asked, only a few respondents suggested additional values (e.g. peace), affirming the 'fitness-for-purpose' (Funtowicz & Ravetz 1990, Ravetz 1996) of our value set. Notably, however, the value rankings or communal 'value landscapes' of the Haida Gwaii community and the herring industry were similar, while their management preferences differed strikingly, suggesting that the issues underlying the fishery conflict are highly complex and potentially contradictory to stakeholder values. Values may run counter to other interests in some settings, particularly in the highly politicized contexts of resource conflicts. Also, respondents can have similar overarching values but may interpret or apply them differently, depending on local circumstances and the differential benefits and impacts accrued from herring. VEBMA is being refined to address these issues, by exploring the cultural contextualization of values and how values may translate to principles of management (Lam 2016a), and by investigating factors and strategies that may influence how individuals negotiate tradeoffs among multiple desirable priorities for the environment (e.g. Loring & Hinzman 2018). These refinements notwithstanding, the proof-of-concept VEBMA methodology introduced here is an innovative approach that can promote dialogue and transparent decision-making to resolve policy tradeoffs and value conflicts in resource management as decribed in the subsequent sections.

4.2. Ecological implications

EwE ecosystem simulation modelling shows that Pacific herring is an important prey species for various Haida Gwaii or Northeast Pacific predators, particularly hake and marine mammals (Fig. 5). For predators whose modelled diets comprise ≥20 % herring, i.e. dolphins and porpoises, humpback whales, and seals (Fig. 6), as well as top predators (transient orcas *Orcinus orca*), strong declines of ≥35 % baseline values were observed in response to simulated collapse (95 % depletion) of herring (Surma et al. 2018b). This reveals strong potential impacts of herring overfishing that could cascade through predator populations and food web structure (Fig. 4). From the mass-balanced EwE modelling, herring's status as a key forage fish in this ecosystem is equivocal, given its low *SURF* index value, but strong biomass declines in 15 % of non-herring groups upon simulated herring depletion. This reflects the Northeast Pacific food web's diverse forage fish guild (herring, eulachon, sandlance, capelin, smelts, etc.) and generalist feeding strategies of most herring predators. Energy-balanced EwE modelling, however, indicates that Pacific herring is an important energy node in this food web (Surma et al. 2018a), corroborating other studies (e.g. Perez 1994, Anthony et al. 2000, Vollenweider et al. 2011) that place adult herring among the most energy-rich prey species in the subarctic North Pacific.

Herring fishery management strategies with low F and high B_c (Table 1) are conducive to precautionary and ecosystem-based fisheries management, corroborating the Lenfest findings, while the MSY strategies typically employed in Europe, albeit within a precautionary approach, are less so (Fig. 8a). Notably, the non-capture SOK fishery traditionally practiced by coastal BC First Nations has minimal ecological impacts and the *BC* scenario has only modest impacts, although these could become strongly adverse under the existing degree of climate variability (Fig. 8b) and especially projected climate shifts (Fig. 8c). Fishery impacts on herring and its predators are exacerbated by poor primary production and stock assessment errors, which shows the influence of both top-down and bottom-up processes on Pacific herring trophodynamics and the need for precautionary management (Surma et al. 2018b).

Ecosystem modelling demonstrates the critical role of herring in the Northeast Pacific food web and suggests that a foremost consideration in selecting herring fishery management strategies or policy options should be their impacts on not only herring populations, but also ecosystem health. In Table 3, we list some species-specific indicators derived from the MSE outputs, such as herring biomass and recovery and humpback whale recovery. In addition, we examine the impacts of the management scenarios on the marine food web, evaluated as the cumulative impacts on the biomasses of all functional groups. Composite ecosystem health indicators could be based on functional group biomass or primary production thresholds. Proposed ecosystem thresholds derived from emergent properties of marine ecosystems include cumulative biomass and cumulative production curves (Link et al. 2015). Here, we simply use the MSE biomass outputs as proxies for ecosystem status that should be prioritized above stakeholder preferences in fishery decision-making and policy setting, if sustainable management is a guiding norm.

4.3. Management implications

Most Haida Gwaii respondents preferred no commercial herring fishery, at least until herring have sufficiently recovered, followed by only a commercial SOK fishery, which, being non-capture, is more ecologically sustainable and is also a traditional food source (Fig. 11). They similarly preferred the precautionary cutoff thresholds for opening the commercial fishery (Fig. 12). Thus, Haida Gwaii respondents preferred the scenarios modelled to have the least ecological impacts and risks (Table 3). This likely reflects the vulnerability of the community to ecological and cultural impacts from re-opening the Haida Gwaii herring fishery and low socioeconomic benefit under the current license structure and distribution. None of the Haida Gwaii respondents selected the DFO policy or threshold, indicating that they clearly desire a change. When asked, 'How do you think the Haida Gwaii herring fishery should be managed?,' 70% expressed a preference for co-management or full Haida control.

In contrast, herring industry respondents showed satisfaction with the DFO policy, with strong preferences for the DFO strategy and cutoff threshold (Figs. 11 & 12). This may reflect the fact that the industry, through the Herring Conservation and Research Society, partners with the DFO to conduct herring research, assessment, and management activities. Our modelling suggests that the DFO policy is precautionary under existing conditions, with fairly modest ecosystem impacts that could be further reduced with a higher cutoff threshold, but is not precautionary against risks of climate variability and change (Table 3). The local commercial herring fishery catch is approximately 0.25 t km^{-2} yr^{-1} (Kumar et al. 2016), equivalent to roughly 12.5% of the natural mortality, *M*, and ¼ of the forage fish catch recommended by Lenfest (≤50% *M*) (Pikitch et al. 2012). With the Lenfest recommended higher B_c/B_0 of 40%, the probability of fishery closure is much higher than with the 25% threshold (Fig. 9b), which would lead to undesirable socioeconomic instability and unpredictability for commercial fishers.

4.4. Policy implications

VEBMA was developed amidst BC's Pacific herring fishery conflict to encourage evidence-informed policy that considers the ecological, socioeconomic, and cultural values of herring to diverse stakeholders. To resolve the conflict, an alternative pathway is needed that does not alienate any of the stakeholder groups. As the foundation for sustainable fisheries, however, considerations of the ecosystem impacts of alternative management strategies must trump the preferences of all stakeholders. A consilient way forward would consider the common value priorities (Fig. 10) and management preferences (Figs. 11 & 12) of local stakeholders, while also considering the ecological, socioeconomic, and cultural impacts and risks of alternative policy options (Figs. 8 & 9), as synthesized in the VEBMA science-policy table (Table 3). This contrasts with the decision tables often used in participatory fisheries management (Fulton et al. 2014, Punt et al. 2016) and structured decision-making (Gregory et al. 2012) in that it does not offer decision rules, but rather is designed to make transparent ecological and socioeconomic impacts and risks and societal preferences to facilitate stakeholder dialogue and collaborative decision-making. The least desirable policy option would be the *OPEN* or always fishing scenario (preferred by none and with the highest target species and ecological impacts). The DFO policy (preferred by only 1 of the 2 stakeholder groups and with high ecological impacts) would be the next least favourable, followed by only a commercial SOK fishery (not preferred by 1 group, despite low ecological impacts). Both these policy options would likely sustain the current fishery conflict, given the divergent preferences. The next least favoured options, in descending order, are the 2 Lenfest recommended and precautionary cutoff thresholds for intermediate and low information, respectively, and no fishing. This suggests that maintaining the current fishery closure, which was preferred by some members from both groups and has the least ecological impacts, is optimal now.

To illustrate some of the tradeoffs that must be considered when making Pacific herring fishery policy decisions in Haida Gwaii, we look at the no commercial herring fishery scenario in more detail. As seen in Figs. 4 to 6, herring is an important prey species to humpback whales, a charismatic species. Modelled whale population recovery from historical depletion of Northeast Pacific food webs and fisheries resulted in declines of up to 87% in Pacific herring and 72% for piscivorous rockfish (*Sebastes* spp.), as well as cascading effects on many demersal fish groups (Surma & Pitcher 2015). Simulating the impacts of the 4 herring fishery management scenarios on humpback whale recovery reveals that commercial herring fishing does not prevent, but does impede, its recovery (Fig. 13). For humpback whales to increase from 500 t to 900 t, for example, it takes 42, 43, 51, and 56 yr in the *NO FISHING*, *SOK*, *LENFEST*, and *BC* scenarios, respectively, corresponding to delays of 1, 9, and 14 yr compared with no commercial fishing. A commercial herring fishery closure, however, results in foregone fishing revenue for the herring industry

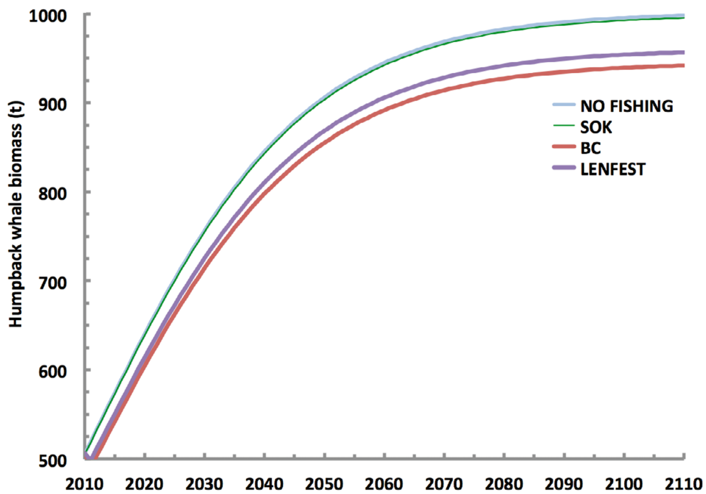


Fig. 13. One herring fishery policy tradeoff: Impact on humpback whale recovery in the Haida Gwaii marine food web of alternative herring fishery management scenarios

(wholesale value of $68.7 million CDN in 2017; British Columbia Ministry of Agriculture 2019), but could lead to growth in ecotourism revenue with more humpback whale sightings. There also would be more herring available for First Nations food, social and ceremonial allocation of SOK, described by 1 Haida interviewee as 'soul food and sustenance for us.' The VEBMA science-policy table (Table 3) makes transparent such policy tradeoffs to facilitate evidence-informed and inclusive decision-making.

For sustainable management of a desirable and viable herring fishery in the future, we recommend exploring the compromise option of managing the roe herring and SOK fisheries separately, with distinct HCRs, and cutoff thresholds between 25 and 75%. More specifically, given the complete dissatisfaction of Haida Gwaii community members with the 25% threshold (Fig. 12) and the high probability of fishery closure for the Lenfest recommended 40% threshold (Fig. 9b), we propose more precautionary EBFM strategies within the narrower range of B_c/B_0 = 30–35% for the roe herring fishery and <30% for the SOK fishery. The precise thresholds and HCRs should be decided within a participatory setting with DFO and the herring industry, affected local and indigenous communities, and other stakeholders, informed by ecosystem simulation modelling to evaluate their ecological and socioeconomic impacts and risks. Note that since this research was completed, and perhaps partially in response to it, DFO scientists have recommended a cutoff threshold of 30% to avoid 'serious harm' to the BC Pacific herring stocks (Kronlund et al. 2018).

4.5. Governance implications

VEBMA resonates with the 'post-normal science' approach (Funtowicz & Ravetz 1993, Gluckman 2014) to wicked problems at the science-policy interface, where facts are uncertain, values are in dispute, stakes are high, and decisions are urgent. In fisheries, despite this uncertainty and complexity (Ludwig et al. 1993, Pikitch et al. 2004), contested decisions surrounding fishery openings, total allowable catches, and quota shares must be made before each fishing season (Hauge 2011, Dankel et al. 2012). To facilitate ethical governance (Lam & Pauly 2010, Lam & Pitcher 2012), we sought input from an 'extended peer community' across academic disciplines, local and indigenous communities, industry, government, and civil society. To better inform decision-making among the fishery policy choices, the quality of the knowledge (EB impacts and risks and VB preferences) was assessed and displayed in the upper right hand corner of each cell in the VEBMA science-policy table (Table 3).

By integrating the values, knowledge, and perspectives of stakeholders with ecosystem considerations to set management objectives and strategies, VEBMA delivers a generalizable deliberation and decision-support tool, with particular merit when values or interests conflict. Making explicit the plurality of values that permeate the science-policy interface can reduce politically biased decision-making. VEBMA also reduces outcome uncertainty (Punt et al. 2016) by exposing values and potential sources of conflict that are masked when stakeholders advocate for specific management strategies. The VEBMA science-policy table reveals the differential impacts of policy options on society and the ecosystem to help decision-makers resolve fishery tradeoffs and conflicts. It can foster dialogue and deliberation among stakeholders affected by resource decisions, such as local communities, industry, NGOs, scientists, managers, and policy makers. VEBMA thus synthesizes and explicates diverse knowledge and value perspectives to foster accountability, trust, and ultimately, ethical governance.

Acknowledgements. We gratefully acknowledge the Haida Gwaii and herring industry research participants for so generously sharing their time, experiences, and perspectives; the Council of the Haida Nation (particularly Russ Jones, Catherine Rigg, and Molly Clarkson); the Herring Industry Advisory Council, notably Greg Thomas; and retired fisherman Joe Bauer. We thank Kate Millar and Sahir Advani for contributing to the Haida Gwaii workshops and for being sounding boards for the values research, Jim McIsaac for his comments on an early draft, and Thomas Potthast for his feedback on an earlier version of our manuscript and fruitful discussions on values and ethics. We appreciate also the comments and consequent improvements to the manuscript from the 4 anonymous reviewers, the Theme Section guest editors, and the MEPS editorial staff.

This research was co-funded by the following: University of British Columbia Peter Wall Institute for Advanced Studies Solutions Initiative Project, *Collaborative Solutions for Haida Gwaii Herring Fisheries* (VEBMA conceptualization & VB research in Haida Gwaii; Principal Investigators [PIs]: M.E.L., T.J.P. & E.A.P.); Natural Sciences and Engineering Research Council of Canada (NSERC) Strategic Partnership Grant, *Understanding the Ecosystem Role of Pacific Herring in Coupled Social-ecological Systems: Advancing Forage Fish Science* (#447247) (EB research & VEBMA science-policy synthesis; PI: T.J.P.); NSERC Discovery Grant, *The Dynamics and Restoration Ecology of Marine Ecosystems* (#140979-2012 RGPIN) (VEBMA synthesis; PI: T.J.P.); Mitacs Accelerate Grant, *Identifying Stakeholder Values in British Columbia Herring Fisheries*, supported by the T. Buck Suzuki Environmental Foundation and Skipper Otto's Community-supported Fishery (VB research with herring industry stakeholders; PI: M.E.L.); University of British Columbia Sustainability Research Grant, *Fostering Sustainable British Columbia Herring Fisheries with Cultural Narratives and Images* (culturally responsive artwork; PIs: M.E.L., T.J.P. & E.A.P.); and European Commission Marie Skłodowska-Curie Individual Fellowship project, *Enhancing Seafood Ethics and Sustainability* (*eSEAS*)*: A Values and Ecosystem-based Management Approach* (#753937) (VEBMA analysis and ethical governance; PIs: M.E.L. & M.K.). University of British Columbia Behavioural Research Ethics Board approval was obtained for the participatory research: certificate #H15-00525.

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Editorial responsibility: Martin Quaas (Guest Editor), Kiel, Germany

Submitted: October 17, 2017; Accepted: April 17, 2019
Proofs received from author(s): May 24, 2019