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Contribution to the Themed Section: '*Case studies in operationalizing ecosystem-based management*'

Original Article

Ecosystem considerations in Alaska: the value of qualitative assessments

Stephani G. Zador[1]*, Kirstin K. Holsman[1], Kerim Y. Aydin[1], and Sarah K. Gaichas[2]

[1]*Resource Ecology and Fisheries Management Division, Alaska Fisheries Science Center, National Marine Fisheries Service, NOAA, 7600 Sand Point Way NE, Seattle, WA 98115, USA*

[2]*Ecosystem Assessment Program, Northeast Fisheries Science Center, National Marine Fisheries Service, NOAA, 166 Water Street, Woods Hole, MA 02543, USA*

**Corresponding author: tel: + 1-206-526-4693; fax: + 1-206-526-6723; e-mail: stephani.zador@noaa.gov.*

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The application of ecosystem considerations, and in particular ecosystem report cards, in federal groundfish fisheries management in Alaska can be described as an ecosystem approach to fisheries management (EAFM). Ecosystem information is provided to managers to establish an ecosystem context within which deliberations of fisheries quota occur. Our goal is to make the case for the need for qualitative ecosystem assessments in EAFM, specifically that qualitative synthesis has advantages worthy to keep a permanent place at the fisheries management table. These advantages include flexibility and speed in responding to and synthesizing new information from a variety of sources. First, we use the development of indicator-based ecosystem report cards as an example of adapting ecosystem information to management needs. Second, we review lessons learned and provide suggestions for best practices for applying EAFM to large and diverse fisheries in multiple marine ecosystems. Adapting ecosystem indicator information to better suit the needs of fisheries managers resulted in succinct report cards that summarize ecosystem trends, complementing more detailed ecosystem information to provide context for EAFM. There were several lessons learned in the process of developing the ecosystem report cards. The selection of indicators for each region was influenced by geography, the extent of scientific knowledge/data, and the particular expertise of the selection teams. Optimizing the opportunity to qualitatively incorporate ecosystem information into management decisions requires a good understanding of the management system in question. We found that frequent dialogue with managers and other stakeholders leads to adaptive products. We believe that there will always be a need for qualitative ecosystem assessment because it allows for rapid incorporation of new ideas and data and unexpected events. As we build modelling and predictive capacity, we will still need qualitative synthesis to capture events outside the bounds of current models and to detect impacts of the unexpected.

Keywords: Alaska, ecosystem approach to fisheries, ecosystem assessment, ecosystem-based fisheries management, ecosystem report cards.

Introduction

The high volume and high value commercial groundfish fisheries in Alaska are both biologically and economically important to the United States and managed through policies at the forefront of ecosystem-based fisheries management (EBFM) efforts. In 2014, these fisheries caught 2.25 million metric tons, with total ex-vessel value of $937.5 million (Fissel *et al.*, 2015) of species such as walleye pollock *Gadus chalcogramma*, Pacific cod *Gadus macrocephalus*, arrowtooth flounder *Atheresthes stomias*, sablefish *Anoplopoma fimbria*, and rockfish *Sebastes* spp. The fisheries are managed by the North Pacific Fishery Management Council (Council), one of eight regional councils established by the Magnuson-Stevens Fishery Conservation and Management Act in 1976 to manage fisheries in the 200-mile Exclusive Economic

Zone (NOAA, 2015). The Council reviews and manages fisheries issues in four large marine ecosystems (LMEs) in Alaska—the eastern Bering Sea (EBS), Aleutian Islands (AI), Gulf of Alaska (GOA), and Arctic—year-round but sets all quotas annually in December for the following year after review of individual stock assessments as well as economic and ecosystem information. Other important fish stocks in Alaska are directly managed by different entities (e.g. Pacific halibut *Hippoglossus stenolepis* by the International Pacific Halibut Commission and salmon *Oncorhynchus* spp. by the state of Alaska) but are under the purview of the Council as ecosystem or bycatch concerns.

Practicing sustainable fisheries, including conserving protected species and habitat is mandated in the United States, in particular under the 2006 amendment of the Magnuson-Stevens Fisheries Conservation and Management Act (1976). In most cases, achieving this goal requires inclusion of ecosystem and non-target species information into management decisions (Link, 2010; Link and Browman, 2014). There are multiple approaches for including ecosystem information in fisheries management, and Link (2010) delineates these approaches along a continuum from single-species fisheries management to ecosystem-based management (EBM). This includes ecosystem approach to fisheries management (EAFM)—where ecosystem information provides the context for single-species management advice; EBFM—where indirect and direct interactions between fisheries, non-target species, and ecosystem processes inform harvest recommendations; and EBM—where multisectoral trade-offs, pressures, and interactions are considered jointly (Link, 2010; Link and Browman, 2014). These approaches require a variety of tools, including risk assessments, management strategy evaluations, ecosystem models, and indicators (Smith *et al.*, 2007; Fulton *et al.*, 2011; Fay *et al.*, 2014; Plagányi *et al.*, 2014). Scientific advice can range from strategic (broad-scale) to tactical (directed at specific management decisions; Hollowed *et al.*, 2011; Plagányi *et al.*, 2014).

There is already a suite of policies and actions currently in practice in Alaska that might be characterized as EBFM or EAFM using these definitions. These include, for example, time and area closures, total fisheries catch limits, a ban on forage fish harvest, bycatch reduction measures, and modifications to fishing gear (Belgrano and Fowler, 2011). There are also regional fishery stock assessments that incorporate ecosystem data, and ecosystem-modelling activities aimed at including environmental pressures on evaluation of stock productivity and concomitant harvest recommendations. A Fisheries Ecosystem Plan was developed for the AI ecosystem in 2007 (AIFEP Team, 2007); another Fishery Ecosystem Plan is currently under development by the Council for the EBS. The Fishery Ecosystem Plan is expected to formalize and strengthen the delivery of ecosystem information to the Council [currently a cooperation between the ecosystem subcommittee of the Council and the Alaska Fisheries Science Center (AFSC) of the National Oceanic and Atmospheric Administration (NOAA)] and will provide a transparent tool for evaluating emergent trade-offs between conflicting management objectives (e.g. conservation and fisheries harvest) and for refining fisheries advice under changing climatic conditions.

The AFSC provides scientific information to the Council to inform the fisheries management process. Currently, one of the central avenues for providing ecosystem science to the Council is through an Ecosystem Considerations report that is presented to managers as part of the collection of stock assessments and economic data produced annually (Belgrano and Fowler, 2011; Zador, 2015). The Ecosystem Considerations report provides a review of ecosystem status as context for quota-setting deliberations, serving as a type of EAFM advice. The report has a long history with the Council, relative to other regions in the country. It was first produced in 1995 as a compendium of Alaska marine ecosystem information and discussion of EBM (Belgrano and Fowler, 2011). In its substantially revised current version, the report includes indicator-based assessments and report cards, and detailed contributions from a broad range of scientists that encompass survey data, model output, and derived ecosystem indicators. Ecosystem information is presented in varying levels of detail, from succinct report cards to detailed indicator descriptions. The information is compiled and synthesized, then presented sequentially for review to several Council bodies, most notably regional Plan Teams and the Scientific and Statistical Committee, which are composed of a diverse group of experts including scientists from government agencies and academia. The process of annual production and review results in the adaptive nature of the report, as evidenced by its evolution over the years. This allows the report to be flexible to new priorities, data, models, and needs as expressed through the frequent communication between AFSC scientists and the Council.

The goal of the Ecosystem Considerations report is to provide stronger links between ecosystem research and fishery management and to spur new understanding of the connections among ecosystem components by synthesizing results of many diverse research, survey, and modelling efforts (Zador, 2015). Trends are monitored with ecosystem indicators, defined here as simply a representation of an ecosystem component measured through time. Indicators can be based on data or derived values, represented in time-series format. They have been widely used to compare ecosystem status across and within ecosystems (Link, 2005; Shin *et al.*, 2010b) and serve as essential components in EAFM and integrated ecosystem assessments (Levin *et al.*, 2009; Fogarty, 2013). Methods for selecting indicators range from formalized processes such as the drivers, pressures, status, indicators, response (DPSIR) approach (Elliott, 2002; Livingston *et al.*, 2005) to surveys of experts (Teck *et al.*, 2010; but see Stier *et al.*, 2016). Indicators are used as an efficiency measure when the ecosystem component in question either cannot be measured directly or to forecast a future state. For example, annual abundances of large copepods may be represented by a time-series of trends in survey abundance. The trends in survey abundance of large copepods may foretell overwinter survival of age-0 walleye pollock (Heintz *et al.*, 2013), which in adult form comprise the second largest single-species fishery by biomass worldwide (FAO, 2014). In the context here, a good indicator is one in which there is clear understanding of what it representing, either as a prediction or description of an important ecosystem component (Link, 2010). Additionally, to be useful to management, indicators should be relevant within the management framework (Rice and Rochet, 2005). In this Alaska example, the annual management cycle necessitates indicators that are updatable annually and preferably not more than one calendar year old. Ecosystem information that represents older ecosystem status is useful in a heuristic sense but is not particularly relevant when quotas have already been set and fished.

Thus, the Ecosystem Considerations report, and the assessments and indicators contained within, are based on quantitative data and complex models but the information is applied as qualitative advice (i.e. to provide context for EAFM). When ecosystem status, and any potential concerns, are presented prior to the stock assessment harvest recommendations, the review of the quantitative harvest recommendations are evaluated in the context of the current status of the ecosystem. The evaluation is in the form of discussion among Council body members, which can influence the quota-setting process during deliberations, and is described further herein. An active area of research is the development of explicit ecosystem thresholds that trigger a specific management response, such as a percent decrease in quota (Large *et al.*, 2013; Fay *et al.*, 2014). Incorporation of these thresholds will change the nature of the application of ecosystem information in the future (Large *et al.*, 2013).

Our goal is to make the case for the need for qualitative ecosystem assessments in EBFM/EAFM, specifically that qualitative synthesis has advantages worthy to keep a permanent place at the fisheries management table, in concert with the development of quantitatively sophisticated modelling efforts. These advantages include flexibility and speed in responding to and synthesizing new information from a variety of sources. First, we use the development and production of indicator-based ecosystem report cards as a current, working example of adapting ecosystem information to management needs. In this particular case, report cards serve a need to succinctly summarize the ever-expanding ecosystem information available to fisheries managers. Second, we review lessons learned and provide suggestions for best practices for applying EAFM to large and diverse fisheries in multiple marine ecosystems.

Methods

In 2010, AFSC scientists met with the Council, to propose modifications to the existing method of conveying ecosystem status (the Ecosystem Considerations report) to improve its utility to the Council. Prior to 2010, the ecosystem indicators within the report were selected using the DPSIR approach (Elliott, 2002; Livingston *et al.*, 2005). Although this approach was able to identify myriad indicators of ecosystem change, many of the indices were repetitive and did not integrate multiple interactions into biological terms meaningful to fisheries managers. The AFSC scientists proposed a more regionalized approach to streamline and synthesize information at the ecologically based scale of LME (Figure 1), rather than at the fisheries management scales, some of which cross LMEs (e.g. the BSAI designation for a stock whose range is in both the Change to EBS and AI).

The general approach was to use teams of ecosystem experts to select short lists of indicators for the EBS, AI, and GOA LMEs. The top 8–10 selected indicators were used to develop succinct ecosystem report cards and serve as the basis for 5–10 page integrative ecosystem assessments. Candidate indicators were collated from existing indicators or knowledge of existing models and/or data that could be used to derive indicators. Indicators were sorted into broad categories: physical processes such as climate and oceanography, lower trophic organisms such as phytoplankton and zooplankton, benthic organisms, fish foraging guilds, seabirds, marine mammals, and human dimensions. Features of non-existent but desired indicators were suggested as needed to fill gaps or improve on existing indicators.

Participants on the expert teams were selected to represent diverse scientific, management, and fishing expertise in the ecosystems from within and outside AFSC. Teams were developed for the EBS in 2010, for the AI in 2011, and for the GOA in 2014–2015. Structuring themes were chosen to help guide indicator selection; these were “ecosystem productivity” for the EBS, “spatial variability” for the AI, and “complexity” for the GOA. Teams selected indicators either in person during 1–2 workshops or by voting in an online query. The goal of the workshops and online

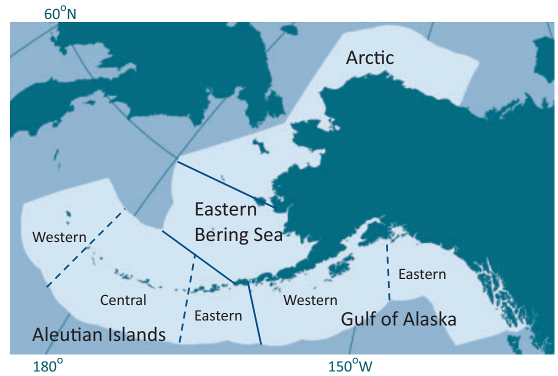

Figure 1. LMEs and ecoregion boundaries in Alaska. Highlighted area indicates the extent of the 200 nautical mile Exclusive Economic Zone.

query was to determine the top ecosystem indicators to serve as vital signs for regional fisheries managers with respect to the structuring theme (see Results for the reasoning behind the theme selection). The top indicators for each category were selected by consensus for the EBS and AI, and by highest numbers of votes for the GOA. The selected indicators for the GOA were further refined by review of a group of 28 scientists involved in a co-occurring integrated ecosystem research program in the GOA.

The final lists of indicators were presented in report cards. Each report card is composed of the indicators and bulleted text; no “grades” or other type of comparable valuations are included despite the name. The indicators are displayed in an annualized time-series format that depicts the long-term mean, recent 5-year trend, and recent 5-year mean relative to long-term mean (Figure 2). Bulleted lists that accompany the time-series briefly summarize some or all of the following: status, factors influencing trends, and implications for fisheries managers. Further detail is contained within the associated ecosystem assessments, which qualitatively integrate information from the report cards with additional information from other indicators, observations, and model outputs in an expanded synthesis.

The report cards were first presented to the Council in the year that each was developed. The Council reviews provided suggestions that were incorporated into the development of subsequent report cards. All report card indicators were and continue to be updated as possible each year. Indicators are replaced if new methodologies or data become available to improve on the originally selected indicators. Expert teams are planned to reconvene periodically ($\sim$5 years) to revisit the top indicators and propose modifications to the suite to reflect current knowledge.

Results

Adapting ecosystem indicator information to better suit the needs of fisheries managers in Alaska resulted in succinct report cards that summarize trends for the ecosystems in question, complementing more detailed ecosystem information presented to managers to provide context for EAFM/EBFM. The top indicators selected by the teams of ecosystem experts were presented on a single page (per ecosystem or ecoregion) with similar formatting to enable comparisons among indicators. The accompanying

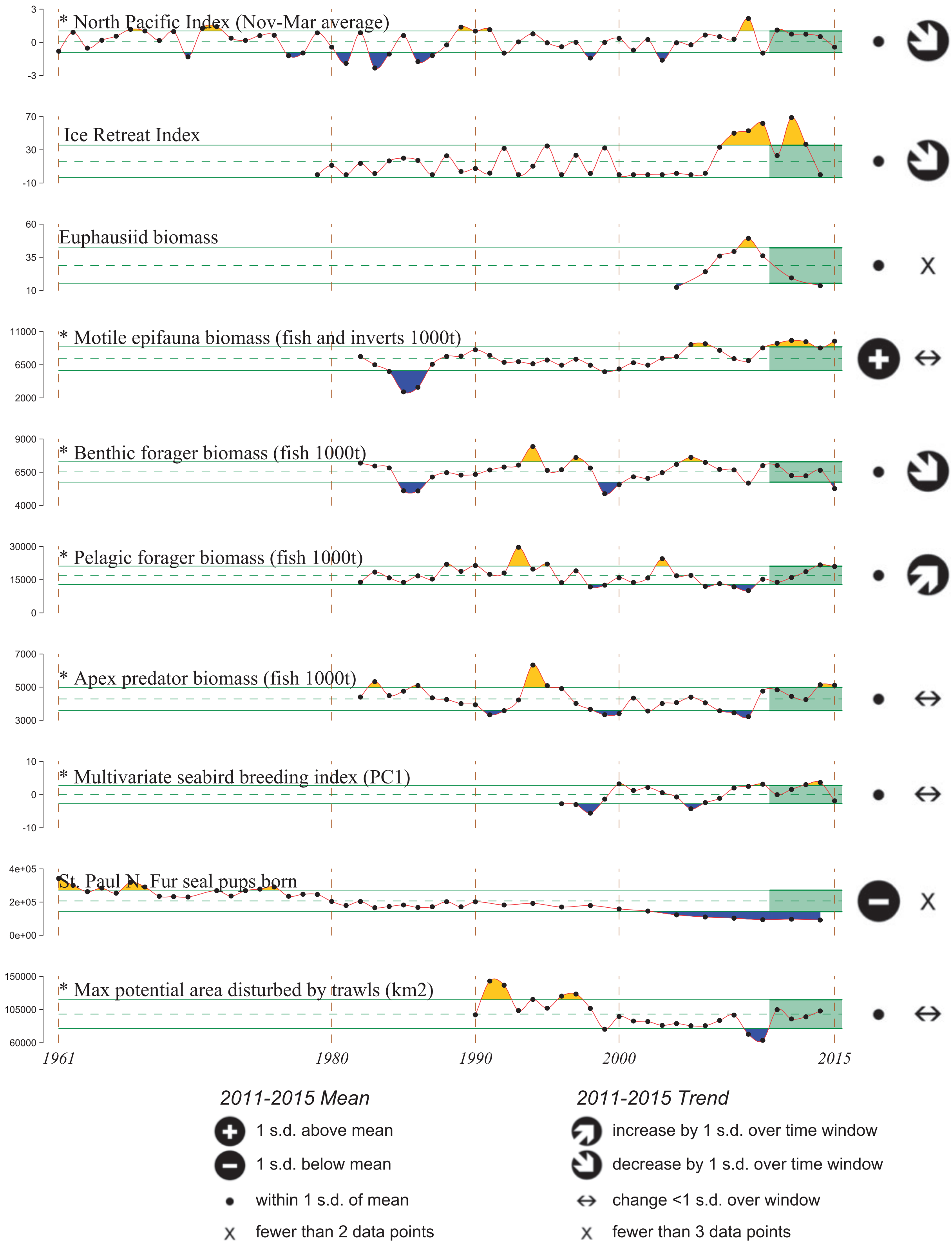

Figure 2. (a) The EBS Report Card. Time-series depict the long-term mean (dashed line), 1 *SD* (solid lines). The last 5 years are shaded. These values are used to calculate the symbols (available at http: http://access.afsc.noaa.gov/reem/ecoweb/Index.php).

Eastern Bering Sea 2015 Report Card

- The **eastern Bering Sea in 2015 was characterized by warm conditions** that were first seen in 2014, and continued through the winter, during which the **PDO reached the highest winter value seen** in the record extending back to 1900.
- The extent of **sea ice during winter was reduced, as was as the size of the cold pool of bottom water** relative to the long term mean during the summer.
- While there was no acoustic survey of euphausiids during summer, rough counts of zooplankton during spring indicated that **small copepods were more prevalent than either lipid-rich large copepods or euphausiids**.
- **Jellyfish remained abundant** during summer, following a new peak fall biomass recorded in 2014.
- **Survey biomass of motile epifauna has been above its long-term mean** since 2010, with no trend in the past 5 years. There has been a unimodal increase in brittle stars since 1989 and for sea urchins, sea cucumbers and sand dollars since 2004-2005.
- **Survey biomass of benthic foragers decreased substantially in 2015, which contributed to the change in their previously stable recent trend to negative.** Recent declines could possibly be related to the consecutive years of springtime drift patterns that have been linked with poor recruitment of flatfish.
- **Survey biomass of pelagic foragers has increased steadily** since 2009 and is currently above its 30-year mean. While this is primarily driven by the **increase in walleye pollock** from its historical low in the survey in 2009, it is also a result of **increases in capelin during the cold years**, which have remained high during the past two warm years.
- **Fish apex predator survey biomass is currently above its 30-year mean**, although the increasing trend seen in recent years has leveled off. **The increase from below average values in 2009** back towards the long term mean is driven primarily by increases in Pacific cod from low levels in the early 2000s.
- **The multivariate seabird breeding index is below the long term mean**, indicating that seabirds bred later and less successfully in 2015. This suggests that **foraging conditions were not favorable for piscivorous seabirds**, a hypothesis further supported by large numbers of dead, emaciated birds observed at sea.
- **Northern fur seal pup production for St. Paul Island remained low** in 2014, indicating that fewer pups were produced in 2014 than during the year of the last survey in 2012.
- The maximum potential **area of seafloor habitat disturbed by trawl gear has remained stable since 2011**.

Figure 2. (b) Summary text that accompanies the EBS report card (available at http: http://access.afsc.noaa.gov/reem/ecoweb/Index.php).

bulleted text provided highlights that could be explored further in the more in-depth ecosystem assessments and detailed indicators descriptions.

The teams of ecosystem experts selected a total of 10, 9, and 10 physical, trophic, and human dimensions indicators for the EBS, AI, and GOA ecosystems, respectively (Table 1). Although the process to generate the report cards was similar among the teams, the resulting products varied. Although each report card was composed of time-series and bulleted text, some LMEs had more than one report card. For the EBS, teams focused on broad, community-level indicators to determine the present state and likely future state of ecosystem productivity (Table 1). Thus, there was one report card to represent the southeastern Bering Shelf area. Following presentations and review of existing physical and biological data, the AI team concluded that significant spatial variability in trophic and physical conditions of the island chain ecosystem warranted grouping indicators by three ecoregions: western, central, and eastern (Figure 1). Ecosystem variability thus served as the structuring theme for indicator selection. Accordingly, the ideal suite of indicators were those for which there are data across all ecoregions and could characterize a global attribute with local behaviour. The final selection included eight indicators represented in three regional report cards and one broad scale climate indicator that could not be reduced into the ecoregion scale. The complexity of the GOA ecosystem, which includes a narrow shelf in the east and wide shelf in the west, major freshwater inputs and large islands and gullies that influence oceanography, allows local scale processes to swamp basin-wide signals. Thus, capturing this complexity was the structuring theme for indicator selection in the GOA and was represented in part by grouping indicators into two ecoregions: western and eastern (Figure 1), which were characterized in two report cards.

Selected indicators for all LMEs included a mix of primary indices (e.g. sea ice retreat timing) and those that integrate multiple processes [e.g. northern fur seal (*Callorhinus ursinus*) pup production] and reflect relative data-availability among LMEs (Supplementary Table S1). In general, the selected EBS indicators were more data-dependent, reflecting the extensive scientific sampling, and knowledge in the region. In contrast, the selected AI indicators were more integrative and indirect (e.g. planktivorous auklet *Aethia* spp. reproductive success as an indicator of zooplankton abundance), reflecting the relative paucity of data in the region. The teams aimed to select broad indicators responsive to changes in structuring processes and reflective of system-wide

Table 1. List of selected report card indicators and definitions.

LME	Indicator category	Indicator	Description
EBS			
	Climate	North Pacific index	November–March average of the area-weighted mean sea level pressure over the region 30°–65° N, 160° E–140° W
	Oceanography	Ice retreat index	The number of days during March and April in which there was at least 20% ice cover in a 100 km box around the M2 mooring located in the southeastern portion of the shelf at 57° N and 164° W
	Zooplankton	Euphausiid biomass	Acoustically determined euphausiid density (no. m^3) averaged over the water column
	Benthic	Motile epifauna biomass	Aggregated biomass of commercial and non-commercial crabs, sea stars, snails, octopuses, and other mobile benthic invertebrates determined from bottom trawl surveys
	Fish	Benthic forager biomass	Aggregated biomass of Bering Sea shelf flatfish species, juvenile arrowtooth flounder and sculpins from bottom trawl surveys
	Fish	Pelagic forager biomass	Aggregated biomass of adult and juvenile pollock, other forage fish such as herring, capelin, eulachon, and sand lance, pelagic rockfish, salmon, and squid from bottom trawl surveys
	Fish	Apex predator biomass	Aggregated biomass of Pacific cod, arrowtooth flounder, Kamchatka flounder, Pacific halibut, Alaska skate, and large sculpins from bottom trawl surveys
	Seabirds	Multivariate seabird breeding index	The dominant trend (first principal component) among 17 reproductive seabird datasets from the Pribilof Islands that include diving and surface-foraging seabirds
	Marine mammals	Northern fur seal pups	The number of fur seal pups born on St Paul Island
	Humans	Area disturbed by trawls	Area of sea floor estimated to be disturbed by trawl gear based on commercial fisheries observer data
AI			
	Climate	North Pacific index	November–March average of the area-weighted mean sea level pressure over the region 30°–65° N, 160° E–140° W
	Zooplankton/ seabirds	Auklet reproductive success	Reproductive success of zooplanktivorous crested *Aethia pusilla* and least auklets *Aethia cristatella*
	Forage fish/ seabirds	Gadids, sand lance *Ammodytes*, Hexagrammids	Percent composition of these forage fish delivered to tufted puffin *Fratercula cirrhata* chicks
	Fish	Pelagic forager biomass	Aggregated biomass of Atka mackerel, Pacific ocean perch, pollock, and northern rockfish from bottom trawl surveys
	Fish	Apex predator biomass	Aggregated biomass of Pacific cod, arrowtooth flounder, Kamchatka flounder, Pacific halibut, skates, large sculpins, rougheye, and black-spotted rockfish from bottom trawl surveys
	Marine mammals	Sea otters	Skiff-based survey counts
	Marine mammals	Steller sea lion non-pups	Counts of adults and juveniles from aerial surveys
	Humans	Area disturbed by trawls	Percent of shelf area deeper than 500 m trawled as determined from commercial fisheries observer data.
	Humans	K-12 school enrollment	The number of children enrolled in schools
GOA			
	Climate	Pacific decadal oscillation	The leading principal component of North Pacific monthly sea surface temperature variability (poleward of 20°N for the 1900–1993 period)
	Oceanography	Freshwater input	Fresh water discharge at the GAK 1 oceanographic station at the mouth of Resurrection Bay near Seward
	Zooplankton	Mesozooplankton biomass	Taxon-specific abundance data collected from Continuous Plankton Recorders
	Benthic	Copepod community size	Mean copepod community size as collected from Continuous Plantkton Recorders
	Fish	Motile epifauna biomass	Aggregated biomass of eelpouts, octopi, crab, sea stars, brittle stars, sea urchins, sand dollars, sea cucumbers, snails, and hermit crabs in bottom trawl surveys
	Forage fish	Capelin	Percent composition that was capelin in diets of tufted puffin *F. cirrhata* chicks at the Barren Islands
	Fish	Apex predator biomass	Aggregated biomass of Pacific cod, arrowtooth founder, halibut, sablefish, large sculpins, and skates in bottom trawl surveys
	Seabirds	Black-legged kittiwake reproductive success	Reproductive success of black-legged kittiwakes *Rissa tridactyla* at Chowiet Island
	Marine mammals	Steller sea lion non-pups	Counts of adults and juveniles from aerial surveys
	Humans	Population	The combined human population of Kodiak, Homer, Yakutat, and Sitka communities

Table **2**. Summary of ecosystem attributes, selection team participants, and indicator foci.

LME	**EBS**	**AI**	**GOA**
Habitat	Broad, flat, muddy shelf.	Extensive rocky island chain, deep trenches, oceanic basins	Broad and narrow shelf area, gullies, major river input, large, and small islands
Data	Extensive	Data-poor	Moderate
Team members:			
NOAA	17	10	23
Academia	2	4	4
Management	1[a]	1	[b]
Industry		1	
Other fed		2	8
Non-profit		1	2
Independent research		1	3
Structuring theme	Production	Variability	Complexity

[a]2 of the NOAA scientists also served on the Council Scientific and Statistical Committee.

[b]1 participating NOAA scientist also served on the Council Scientific and Statistical Committee.

impacts of fishing and climate rather than selecting indices based on data quality *per se* and/or spatial or temporal extent of datasets. Efforts were made to avoid redundancy in indices as well as highlight data gaps where indices lacked spatial or temporal coverage (e.g. indicator was measured in one region but not another).

Indicator selection also reflected the expertise of the teams (Table 2). After the first report card was produced, the Council recommended diversifying the team of experts used for subsequent report card development. Thus, the predominance of research scientists in the team that was convened for the EBS, was lessened for the AI with the inclusion of a commercial fisherman, conservation organization representative, and additional agency scientists. The inclusion of the human dimension indicator, AI school enrollment, resulted from the suggestion from the commercial fisherman. A greater effort to diversify the expertise for the GOA team was accomplished by changing the selection format to an online query, which had a response rate of 42%. This allowed both the number and diversity of team members to increase, although NOAA scientists comprised the majority of respondents.

Discussion

The application of ecosystem considerations, and in particular ecosystem report cards, in federal groundfish fisheries management in Alaska can be described as an EAFM (Link, 2010; Link and Browman, 2014). Ecosystem information is provided to managers (Council) to establish an ecosystem context within which deliberations of fisheries quota occur. This constitutes a qualitative application of quantitative data but with the flexibility and speed to incorporate new information from a variety of sources. For example, a recent warming event in the GOA developed in winter 2014 when surface temperatures were observed to be >3°C above the previous highest recorded temperature (Bond *et al.*, 2015). Observations of immediate ecosystem impacts such as range shifts in highly mobile marine predators were tracked and presented that year to the Council; ecosystem indicator trends were qualitatively evaluated in light of the current unexpected environmental conditions. The AFSC was able to respond quickly to put resources towards more surveys the following summer because of a combination of quantitative forecasts, specifically the 9-month bottom temperature forecast for the EBS that is one of the indicators in the Ecosystem Considerations report, and qualitative information about how the ecosystem might respond to the continuation of warm conditions.

With support from the Council, the development of ecosystem report cards grew out of efforts to reduce myriad ecosystem indicators to a succinct summary that can be delivered to managers alongside more comprehensive information. Ecosystem report cards have been developed in many countries to address a variety of management objectives (see review in Dauvin *et al.*, 2008; Doren *et al.*, 2009; Connolly *et al.*, 2013). The specific goal in Alaska was to increase the visibility and utility of important ecosystem data, by making the information more consistently presented, transparent, and comparable between indices. These summaries, though not depicting quantitative scores or grades, give fisheries managers, or other interested parties, a quick way to review current ecosystem status relative to trends over time and note any warning signs. In theory, success could be measured by a documented increase in the number of views of the report cards or Council time spent discussing ecosystem information, which is currently unknown. However, an indirect measure of success could be inferred by the current development of similar report cards for individual groundfish and crab stocks in other divisions within AFSC, which the Council has encouraged. Additionally, similar formats have been adopted by NOAA efforts in the West Coast to inform the Pacific Fishery Management Council (Harvey *et al.*, 2014; Garfield and Harvey, 2016).

There were several lessons learned in the process of developing the ecosystem report cards for the EBS, AI, and GOA. First, despite using similar methods, the resulting products varied substantially among ecosystems. Most notably, while the EBS was presented in a single report card for the LME, the AI, and GOA were represented in 3 and 2 report cards, respectively, that capture ecoregion-scale differences within the LMEs. Second, the selection of indicators for each region was influenced by geography, the extent of scientific knowledge/data, and the particular expertise of the selection teams. Significant differences in physical habitat and ecosystem attributes limited generalizing indicators to a single suite across LMEs in the AI and GOA. Regions with less data available such as the AI led to selection of more integrative and indirect indicators. Finally, more diverse expertise in the selection teams led to more diverse indicators selected.

Understanding the management system

Optimizing the opportunity to incorporate ecosystem information into management decisions requires a good understanding of the management system in question. This understanding can help scientists to structure ecosystem information to best fit within the cycles and processes of the management system, which leads to more useful, and ultimately usable, information. In other words, it is likely more efficient to adapt scientific information to the spatial and temporal scales of the management system at hand, than to hope to adapt a management process to fit scientific data. This is particularly relevant to tactical management advice, which is geared towards specific and immediate needs of decision-makers, as opposed to strategic advice, which has relevance over longer time scales (Plagányi *et al.*, 2014). The need for regionally specific and adaptable ecosystem management tools has been widely documented (Smith *et al.*, 2007; Fulton *et al.*, 2011; Walther and Möllmann, 2013; Dickey-Collas, 2014). In the case of federal groundfish fishery management in Alaska, the annual cycle of stock assessment review and quota setting means that ecosystem indicators need to be up to date or at most a year old to be relevant to quota deliberations on present day conditions. Ecosystem information that is 2 or more years old retains heuristic value but less relevance to immediate management decisions as previous quotas have already been set and fished.

A small but important factor in communicating ecosystem information to fisheries managers is that the order of information delivery matters. Ecosystem information needs to be presented before quota setting to allow for qualitative inclusion by setting context for quota deliberations. Receiving reports or presentations after quota deliberations, whether separated by hours or months, creates a missed opportunity for contextual inclusion. Although this is particularly relevant with oral or other fixed-time presentations, it is also relevant to written communications that may be delivered at different times in a management process.

What has and has not worked

The abbreviated format of the report cards limits, by design, the amount of information that can be conveyed. They are too short to be complete representations of ecosystem state, but the accompanying text in the integrative ecosystem assessments allows for the addition of synthesis as well as the inclusion of new and noteworthy events or data that may signal red flags or issues that may influence management decisions, including those that are not standard annualized time-series. The report cards and assessments also serve as an organizing structure for connecting process research to management, with the result in this case that the Council is not isolated from the scientists.

For now, the delivery of information via the Ecosystem Considerations report remains firmly EAFM, in that explicit use of report cards for tactical quota decisions has not occurred due to lack of quantitative ecosystem thresholds but this is an active area of research (Large *et al.*, 2013; Fay *et al.*, 2014). This lack of established tactical application is the main challenge for qualitative assessments. Inclusion of qualitative assessments may be considered sufficient to define a management process as EAFM without explicit examples of how the information has influenced management. Although to date explicit examples are rare in Alaska's groundfish management, the inclusion of ecosystem information through discussion has led to quota adjustment in some years. The most clear example occurred in 2006, when a combination of modelling output and ecosystem indicator status led to a reduction of the quota of EBS walleye pollock from the amount recommended in the walleye pollock stock assessment model. In this case, the Council noted that: the results from the stock assessment indicated a 19% decline in the stock and a northward shift of some of the stock into Russian waters; ecosystem indicators showed a large decline in zooplankton, which are important prey for juveniles; and a multispecies model documenting increased predation by arrowtooth flounder on juvenile pollock. The qualitative combination of information was deemed sufficient justification to reduce the quota for the following year.

Regular presentation of ecosystem information may also have more indirect influence on management on a longer time frame. For example, in Alaska many commercially fished stocks share quota between two LMEs, such as sablefish in the EBS and AI. Regular discussion of the two LMEs that emphasize the difference between the LMEs may facilitate future discussions regarding splitting quota by these LMEs by establishing the differences in trends, as recently occurred with Pacific cod, whose AI stock, and allowable catch, is now assessed separately from the EBS (Thompson and Palsson, 2013).

Suggestions for best practices

Communication and visual presentation is important for making ecosystem information more useful (and concise, in the case of report cards), which in turn results in the product being used more (whether defined by inclusion in discussion or dissemination through multiple communication channels). Methods for presenting ecosystem information vary widely, from simple pie charts (Shin *et al.*, 2010a) and stoplight figures (Tierney *et al.*, 2009) to more complex, web-based platforms (e.g. the Chesapeake Bay Report Card; ecoreportcard.org/report-cards/chesapeake-bay, accessed 21 June 2016). We have found that frequent dialogue with managers and other stakeholders leads to adaptive products suited to the end user. In the case described here, the goal was to select indicators to best represent qualities of interest for the ecosystem in question. The resulting selection would have included different indicators if the goal was to be able to compare ecosystem states across ecosystems, such as is the case for efforts such as INDISEAS (www.indiseas.org) or the Ocean Health Index (www.oceanhealthindex.org; Shin *et al.*, 2010b; Halpern *et al.*, 2012).

In our experience, suggestions for best practices for incorporation ecosystem considerations into fisheries management include frequent communication, flexible products that allow for adaptation to both new management concerns and new scientific information, matching temporal and spatial scale of ecosystem information with the management process, and considering carefully the timing and order of how ecosystem information is presented to managers with respect to the management cycle. The initial buy-in from the primary stakeholder (Council) and frequent communication through the annual review cycle allows ecosystem products to be tailored to needs of federal fisheries managers in Alaska. One example is increasing interest in human dimensions (Hicks *et al.*, 2016). The inclusion of the AI school enrollment indicator in the AI report card received substantial questioning when introduced in 2011. In contrast, the further development of human dimension indicators was specifically requested when the first GOA report card was presented in 2015. In addition, we recommend incorporating a standardized process to document management responses to report cards and/or qualitative ecosystem assessments in general (Connolly *et al.*, 2013).

We believe that there will always be a need for qualitative ecosystem assessment, exemplified in this case by report cards of selected indicators or lengthier integrative ecosystem assessments, which can coexist with increasing model complexity and the development of ecosystem thresholds. Qualitative assessments allows for rapid incorporation of new ideas and data and unexpected events. There is lag time inherent in modelling efforts, specifically the design, development, and testing, which result in powerful tools for ecosystem management once in operation (Smith *et al.*, 2007; Link *et al.*, 2010; Fulton *et al.*, 2011). Models of intermediate complexity have been proposed to limit the complexity and support tactical fisheries management advice (Plagányi *et al.*, 2014). Nonetheless, as we build modelling and predictive capacity, we will still need qualitative synthesis to capture events outside the bounds of current models and to detect impacts of the unexpected.

Supplementary data

Supplementary material is available at the *ICESJMS* online version of the manuscript.

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