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REVIEW

Creel Surveys for Social-Ecological-Systems Focused Fisheries Management

Chelsey L. Nieman[a], Carolyn Iwicki[b], Abigail J. Lynch[c], Greg G. Sass[d], Christopher T. Solomon[a], Ashley Trudeau[b], and Brett van Poorten[e]

[a]Cary Institute of Ecosystem Studies, Millbrook, New York, USA; [b]Department of Marine and Coastal Sciences, Rutgers University, New Brunswick, New Jersey, USA; [c]National Climate Adaptation Science Center, U.S. Geological Survey, Reston, Virginia, USA; [d]Wisconsin Department of Natural Resources, Escanaba Lake Research Station, Office of Applied Science, Boulder Junction, Wisconsin, USA; [e]School of Resource and Environmental Management, Simon Fraser University, Burnaby, British Columbia, Canada

ABSTRACT

Recreational fisheries are social-ecological systems (SES), and knowledge of human dimensions coupled with ecology are critically needed to understand their system dynamics. Creel surveys, which typically occur in-person and on-site, serve as an important tool for informing fisheries management. Recreational fisheries creel data have the potential to inform large-scale understanding of social and ecological dynamics, but applications are currently limited by a disconnect between the questions posed by social-ecological researchers and the methods in which surveys are conducted. Although innovative use of existing data can increase understanding of recreational fisheries as SES, creel surveys should also adapt to changing information needs. These opportunities include using the specific temporal and spatial scope of creel survey data, integrating these data with alternative data sources, and increasing human dimensions understanding. This review provides recommendations for adapting survey design, implementation, and analysis for SES-focused fisheries management. These recommendations are: (1) increasing human dimensions knowledge; (2) standardization of surveys and data; (3) increasing tools and training available to fisheries scientists; and (4) increasing accessibility and availability of data. Incorporation of human dimensions information into creel surveys will increase the ability of fisheries management to regulate these important systems from an integrated SES standpoint.

KEYWORDS
Social-ecological systems; recreational fisheries; human dimensions; management

Introduction

Fisheries inherently encompass ecological and social processes as well as the interactions and feedbacks between the two. Sustainable management of social-ecological systems (SES) should therefore account for ecological dynamics and human dimensions (Hunt et al. 2013). The concept of human dimensions is interdisciplinary and includes multiple fields within the social sciences (Bennett et al. 2017); this review focuses on those processes that drive human behaviors (e.g., values, attitudes, economic considerations). Although strategies have emerged for managing recreational fishery SES (e.g., Arlinghaus et al. 2017), many fishery SES are lacking in the fundamental data necessary to implement these strategies.

Creel surveys are a common tool used to assess the status of recreational fisheries and inform management through interviews with, or counts of, anglers to determine effort, catch, and harvest in a given system. Creel surveys have long functioned as an important connection between ecological and social aspects of fisheries. As thinking about fisheries has changed to an increasingly SES viewpoint, shifts in desired fisheries outcomes are occurring that alter the way these systems are managed (Ward et al. 2016). SES thinking is driving important innovation within recreational fisheries research and management (e.g., Hunt et al. 2013; Arlinghaus et al. 2017). SES are inherently complex and therefore difficult to manage, partially due to uncertainty in feedbacks and responses to change (Schlüter et al. 2012). Managers are increasingly interested in the connections between angler behavior and preferences (Fedler and Ditton 1994), adaptive governance (Arlinghaus et al. 2017), cultural implications (Poe et al. 2014), and economic valuation of recreational fisheries (Navrud 2001). Adaptive fisheries management is now being used to manage not only ecological systems, but also to manage social systems and their response to change across the landscape (Martin and Pope 2011; Mee et al. 2016).

CONTACT Chelsey L. Nieman niemanc@caryinstitute.org Cary Institute of Ecosystem Studies, 2801 Sharon Turnpike, Millbrook, NY 12545.

Understanding social responses can increase a manager's ability to respond proactively to feedbacks within SES.

Creel surveys can be conducted systematically as a part of on-going fishery monitoring (e.g., Kempinger and Carline 1977; Cass-Calay and Schmidt 2009), or can be done opportunistically, as needed for proposed management actions (e.g., Petering et al. 1995). Creel surveys are widely considered the most efficient way for managers to understand harvest dynamics within recreational fisheries (Hartill et al. 2016), and many have been continually operating for decades (Kempinger and Carline 1977). These surveys take many forms, including types that necessitate contact with anglers, such as compulsory (e.g., all anglers of a waterbody required to participate in creel survey) (Kempinger and Carline 1977), access-point, mail-in, angler diary, telephone, and door-to-door surveys, as well as non-contact surveys such as aerial boat and angler counts and camera or traffic monitoring (Pollock et al. 1995; Ditton and Hunt 2001; Hartill et al. 2011; Gaeta et al. 2013; van Poorten et al. 2015; Hartill et al. 2016; van Poorten and Brydle 2018). This review focuses on one of the most common types, the angler-intercept survey. Although the benefits of creel surveys are widely accepted, they are time intensive and associated with relatively high operational costs. In times of decreasing budgets, there is an increasingly critical need to refine creel survey methodology and the use of their data. Efforts have been made to assess the accuracy and value of different survey methodologies within different recreational fisheries, with different management challenges of individual fisheries resulting in different survey formats used by managers (e.g., Newman et al. 1997; Eckelbecker 2019). Although individual fisheries have designed surveys to meet specific management needs within their respective systems, missed opportunities have arisen in the use of these surveys for understanding the complex dynamics of the broader implications of recreational fisheries across the landscape.

Creel survey approaches, however, have not adapted to keep up with the shift toward greater focus on social-ecological interactions. Although maintaining the integrity and traditional purpose of creel surveys is of utmost importance, there are ways to modify their design, implementation, data storage, and analysis to yield improved understanding and management of fisheries as SES. Adaptation of creel surveys to increase human dimensions information (i.e., economic valuation, behavior, attitudes, beliefs, practices, consumptive orientation) and integration of existing data from other non-survey sources can allow managers to meet more expansive ecosystem-based and systems-level management goals. These data can provide key insights into how anglers interact with fishery systems and increase the predictive abilities of management to ensure that regulations achieve management objectives. For example, angler motivations can inform the social-ecological feedbacks between effort and angler motivation, a key aspect of maintaining recruitment, retention, and reactivation (R3) strategies (Falk et al. 1989; Fedler and Ditton 2001; Kuehn et al. 2013).

This review highlights the potential for expanding the scope of creel surveys (in particular, angler-intercept surveys) to better understand the social-ecological dynamics of recreational fisheries. This review also includes recommendations for how existing data can be integrated across time and space and highlights opportunities to increase the use of these data in SES research. Further, a road map is provided on how creel surveys can adapt to the new paradigm of SES-focused fisheries research and management. If enacted, these changes would increase accessibility of creel survey data for managers and researchers and the ability of managers to accurately pinpoint the role of angler behavior, motivation, and satisfaction in the dynamics of the SES in which they play a regulatory role.

Opportunities for integrating creel surveys into SES research

Opportunities exist for the expansion of creel survey applications to understand recreational fisheries metrics beyond harvest (see Fig.1). Although the ultimate purpose of angler-intercept surveys is to inform sustainable management of fish populations, there are opportunities to align these data to increasingly diverse fisheries management needs. There is a need to reorient angler-intercept surveys to encompass human dimensions for SES-focused management, thereby promoting sustainable fish populations coupled with sustainable angler populations.

Spatial and temporal scope of data

Creel data exist for many waterbodies and many points in time; however, the scope of use of these data is often narrowly focused in space and time, with most creels targeting specific waterbodies or management actions. With more use of the spatial and temporal scope of creel data, questions could be answered about long-term trends and the scales at which

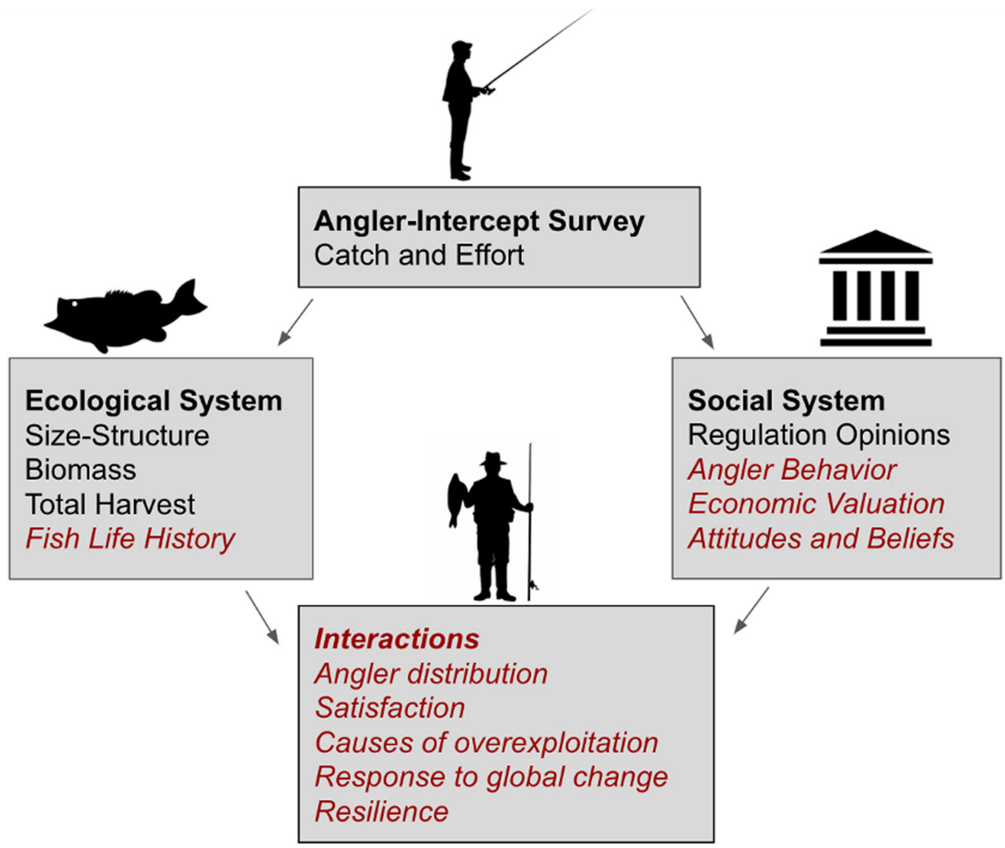

Figure 1. Creel surveys have long been an important tool for fisheries management, but important opportunities exist to update and expand creel survey methods to better inform management of fisheries as social-ecological systems. Currently angler-intercept creel surveys are used to measure catch and effort in order to assess the ecological system (in black font), while opportunities exist for expansion of these surveys (in red). Increasing content to include more human dimensions questions can increase our understanding of interactions between and within the social-ecological recreational fisheries system.

processes operate. With the existence of large datasets comes the opportunity for integration and synthesis of these data, a key to understanding and predicting dynamics in ecological systems (Peters 2010). Although some of these data have been used for synthesis efforts, much of creel data remains to be fully explored. Increasing demand for synthesis endeavors to inform science and policy has illuminated the role that angler-intercept (creel) surveys can play in increasing SES knowledge of these systems.

Long-term planning that integrates individual creel survey datasets across time and space can provide managers with the unique ability to regulate system dynamics across multiple scales and disciplines that intersect with fisheries (Table 1). The scale of a fishery, in many instances, dictates the type and richness of data collected, with small-scale (e.g., individual lake) systems using different creel methodologies than larger systems (e.g., marine nearshore fisheries; Pollock 2002). Although angler interviews allow managers to understand effort at a specific waterbody, the aggregation of many such surveys can also provide information about trends across multiple waterbodies, and can even provide data at a statewide or regional level (CreelCat; USGS, 2020). Identifying patterns within and among waterbodies can aid in the management of data-poor fisheries. Indeed, research has shown that seemingly micro-scale trends in angler behavior result in macro-scale patterns of harvest across regional landscapes (Ward et al. 2016). For example, trends in angler behavior on a seemingly small scale can result in regional overexploitation (Ward et al. 2016) that is not readily apparent without synthesized fisheries data. These emergent trends across the landscape highlight the importance of understanding scale in recreational fishery processes.

There is an increasing impetus to manage fisheries from a regional scale, which can only be accomplished through the use of creel data synthesized across different spatial scales (Table 1). The specific scale of fishery issues might necessitate different spatio-temporal solutions. For example, aquatic invasive species mitigation might necessitate collaboration at a watershed scale, whereas angler distribution across the landscape

Table 1. The hierarchical scale at which managers use creel surveys (including angler-intercept surveys), including examples of their use in research and opportunities for use.

Scale	Current applications	Examples*	Opportunities	Example of supplemental data
National	N/A	CreelCat (USGS, 2020)	National trends in participation, effort, catch. Spatiotemporal relationships between angling and global, demographic change.	U.S. Census Data. National Survey on Recreation and the Environment. National Survey of Fishing, Hunting, and Wildlife Associated Recreation. National Water Quality Monitoring Program Database. USGS Water Quality Data.
Regional	Regional harvest. Aquatic invasive species monitoring.	Great Lakes Fish Commission Creel Bell 1997 – economic valuation of fisheries in the southeastern US	Large scale trends in participation. Regional angler movement. Consumptive orientation.	Great Lakes Environmental Research Lab (GLERL) Water Quality data. MODIS data. NEON.
State	License Sales. Economic impact. Harvest. Resident vs. nonresident anglers.	Fisher et al. 2002 – socioeconomic characteristics of Oklahoma anglers (phone survey)	State level angler participation. Economic valuation of angling. Variation in target species.	CalCofi. State monitoring programs. License sales data. State-run mail-in surveys.
Waterbody	CPUE. Harvest.	Zischke et al. 2016 – drivers of fishery change in Lake Michigan	WTP for fishing in that location. Distance traveled. Site choice characteristics.	Local water quality monitoring. Lake associations. Mark-recapture fisheries biomass estimates.
Individual/Party	Catch. Effort.	Ray et al. 2007 – site specific angler characteristics, health exposure	Satisfaction. Angler behavior. Angler motivations.	Mail-in survey responses.

*This list is not exhaustive, rather it focuses on examples (where available) for each spatial level at which this research occurs.

might be more regional, and not connected to a specific watershed, instead relating more to an "anglershed" (i.e., catchments; or how anglers distribute across the landscape; Pope et al. 2017; Ruskamp 2018; Kaemingk et al. 2019). Catchments can be used to understand not only where anglers are coming from spatially, but can provide managers with key information regarding the distribution and diversity of anglers. A deeper understanding of catchments can allow managers to accurately assess fishing effort and harvest within individual waterbodies, but also trends in fisheries-related attributes such as target species, angler satisfaction, and potentially identify areas in which increases or decreases in effort are likely to occur.

In addition to large-scale opportunities, creel surveys can provide important data regarding the temporal scope of recreational fisheries. Long-term fisheries data have been used to understand trends in fish biomass and responses to management actions (e.g., Haglund et al. 2016; Rypel et al. 2016). For example, long-term (1985-2013) creel data have been used to understand catch characteristics of rainbow trout (*Oncorhynchus mykiss*) in New Zealand, revealing the occurrence of hyperstability in this system (Dedual and Rohan 2016). An opportunity exists, however, to couple long-term fisheries data with human dimensions data to identify underlying mechanisms for changes in angler effort and participation. Temporal data can provide managers with an intimate understanding of fishery trends over time, including catch-and-release practices or target species preferences, and shifts in ecological species composition (Gilbert and Sass 2016; Sass and Shaw 2020). Many creel surveys have been continuously conducted in inland recreational fisheries for decades, providing managers and researchers with a wealth of potential data sources to investigate these temporal trends.

Beyond the scaling-up of creel data, the spatial scope of these data can allow for interesting and innovative investigation of SES. Integration of creel data, and consideration of fisheries as large-scale systems, could increase a manager's ability to understand landscape-level implications of management action such as regulations, angler distributions, and effort dynamics. These landscape perspectives can provide management insights that cross political and geographical boundaries and can increase a manager's ability to regulate from a systems-level. Integrating survey data across regional landscapes could increase the use of these surveys in waterbodies, such as large rivers, that span across political boundaries or management units. Although some effort has been made to increase fisheries thinking that spans full watersheds (e.g., Fussell et al., 2016), there is still more to do to assess these large-scale patterns in fisheries trends.

The large-scale and often long-term data contained in creel surveys could also reveal important trends influencing fishery dynamics that are not tied to specific waterbodies. Creel surveys can be used to investigate social trends, such as changes in technology use across recreational fisheries and resultant catch rates between those using technology and those that are not (e.g., GPS, smartphones, underwater cameras; Feiner et al. 2020). In addition to social trends, large-scale data can also reveal ecological trends and trends in SES feedbacks. Creel surveys can offer a unique look into patterns of fisheries participation across demographic barriers, highlighting the influence of change. For example, in Berlin, Germany, it was determined that rural anglers were more likely to participate in fisheries, but urban anglers were more avid, committed anglers (Arlinghaus and Mehner 2004); fewer urban residents (as a percentage of population) fish, but those who do may have an influence disproportionate to their numbers (i.e., increased time, money, and effort compared to rural anglers). Creel survey data could be used to investigate these patterns, revealing important linkages between human geography and recreational fisheries SES. Combining angler-intercept surveys across different demographics will increase understanding of spatial and temporal patterns, providing improved information for structuring R3 strategies.

Finally, watershed- and regional-level data can be used to decrease bias and to reduce uncertainties related to managing data-poor fisheries. Management agencies inherently have different focus, funding, and goals resulting in a mosaic of varying survey output that can be difficult to standardize. Cost and time limitations can result in the use of trend lakes, with the more "popular" systems (i.e., systems that have higher fishing pressure) being more closely monitored than other systems, likely resulting in bias in understanding of angling pressure. Using existing data to describe landscape-level interactions can reduce the bias and uncertainty related to this mosaic of outputs, increasing their effectiveness. For example, effort data from trend lakes coupled with spatially extensive data collected from less-sampled or data-poor lakes can be used to understand effort across a fishery landscape (Trudeau et al. 2021). This modeling approach can further increase management capacity, while decreasing operational costs.

Optimizing data integration

Large-scale spatio-temporal data sets (e.g., climate, demographic, water quality) are increasingly available and can complement and enrich the understanding gained from creel surveys. Better integration of these data into analyses of creel data would enable increased ability to analyze SES dynamics beyond what is available through traditional creel surveys alone. For many state agencies, limitations to data collection can be a major barrier to increasing human dimensions knowledge such as behaviors, motivations, and attitudes of anglers. The result of this is, in some instances, the current structure of angler surveys that do not encompass the necessary information for SES studies and ecosystem-management (Hall-Arber et al. 2009). Although integration of SES-focused questions into angler-intercept surveys themselves would drastically increase human dimensions understanding, the use of existing data, synthesized with supplemental data can provide insight into this domain.

Supplements to traditional angler-intercept and access-point surveys can provide some of the key human dimensions data such as angler motivations, behaviors, and economic valuation, that is missed through traditional angler-intercept methods. These commonly take the form of mail surveys, email surveys, phone surveys, angler diaries, and the use of fisheries mobile phone apps. For example, mail-in surveys to license holders can increase human dimensions knowledge of the angler base, while not increasing time constraints of angler intercept surveys (Wilde et al. 1996). Although these supplemental surveys have been criticized for overestimating catch (Roach et al. 1999) and can result in nonresponse and recall bias (Connelly et al. 2000), these surveys are currently used by managers to expand beyond the data encompassed in traditional angler-intercept surveys. Minimization of bias can be accomplished through incorporation with other sources of data (Barrett et al. 2017), but must always be considered when using these data. For example, a combination of angler-intercept and mail-in surveys was used to estimate regional economic impacts of a recreational striped bass (*Morone saxatilis*) fishery on Lake Texoma (Schorr et al. 1995). Mail-in surveys (and increasingly electronic surveys) give managers and researchers the opportunity to ask in-depth questions regarding demographics, attitudes, and consumptive orientation (Ditton and Hunt 2001).

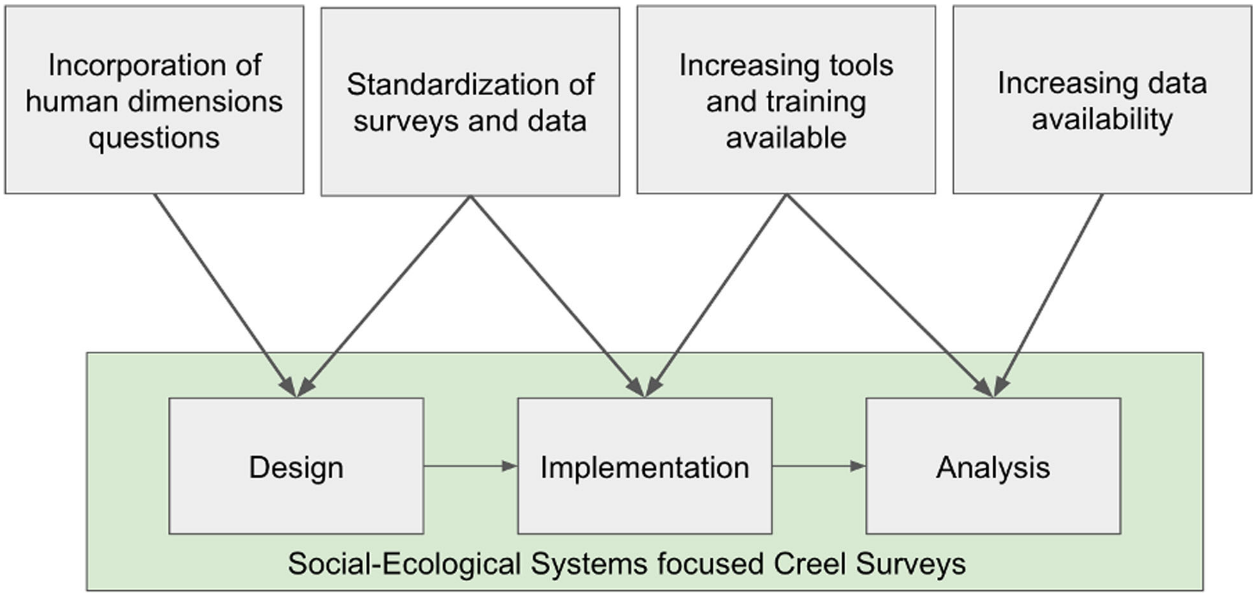

Figure 2. The path forward for creating creel surveys that incorporate social-ecological systems thinking. We recommend the following four steps to incorporating social-ecological systems perspectives into all aspects of creel survey design, implementation, and analysis: (1) increasing human dimensions knowledge, (2) standardization of aspects of surveys and data, (3) increasing tools and training available to fisheries scientists, and (4) increasing accessibility and availability of data.

Many researchers have added supplemental questions to creel surveys to collect data beyond what many state agencies regularly gather. These experimental creel surveys often focus on aspects of fisheries management that are related to species of concern (e.g., Kozfkay and Dillon 2010), or aspects of human dimensions that are not commonly included in regular creel surveys (e.g., Petering et al. 1995). For example, Kozfkay and Dillon (2010) conducted an experimental creel survey that sought to understand whether fishing mortality rates were sustainable in a white sturgeon (*Acipenser transmontanus*) fishery in Idaho. Experimental creel surveys conducted by the Ohio Department of Natural Resources were used to determine angler preferences for catch regarding crappie (*Pomoxis* spp.) fisheries (including lengths and numbers of fish; Petering et al. 1995). In Virginia, experimental creel data were used to assess attitudes of anglers toward the muskellunge (*Esox masquinongy*) fishery in order to understand fishing pressure and the influence of new fishery regulations (Brenden et al. 2007). Large-scale efforts in British Columbia resulted in assessment of fish populations in 21 lakes and 1,956 angler-intercept surveys in order to assess how anglers were likely to move across a fishery landscape (Ward et al. 2013). These experimental datasets provide flexibility, comparable methodology and effort, and more specific information geared toward experimental parameters, and as such, may be an important tool for investigating potential changes to current systematic creel survey design and implementation.

Recently, self-reporting angler apps have been suggested as a low-cost alternative to collecting traditional creel survey data (Venturelli et al. 2017). There has been a major effort to validate the use of these apps to understand whether the app data can be compared to the data traditionally collected through angler-intercept surveys (Papenfuss et al. 2015). These angler apps provide the ability to collect specific data that are related to specific studies, in a relatively cost-effective way (i.e., Papenfuss et al. 2015; Nieman et al. 2020). Further, angler apps can provide additional demographic data that may be more difficult to collect in traditional angler-intercept methods. Issues around the use of angler apps include concerns over the user demographics, user privacy, reliability of data, and certain app-specific features, such as only reporting days in which catch occurs, and not collecting data when catch is zero (Venturelli et al. 2017).

Whereas supplements to creel surveys are important for providing guided knowledge necessary in certain fisheries, integration of existing data with creel data can provide managers with a more thorough picture of the functioning of the entire SES (Figure 2). Comparisons across experimental creel data and agency data can yield information about effort that can be used to generalize across un-surveyed or data-poor waterbodies (Trudeau et al. 2021). Integration across multiple data-sources can yield key angler information, such as economic valuation, values, beliefs, and attitudes that are not yet included in creel surveys, but have been identified as needs by fisheries managers (Heck et al. 2016). Combining harvest data with large-scale climate data can reveal climate driven patterns of harvest of multiple species across the landscape (e.g. CreelCat; USGS, 2020). Integrating demographic data from the U.S. census can reveal how angler participation varies across income level, age, ethnicity, and the urban-to-rural gradient. The use of multiple data sources may also reveal trends of recreational angler welfare that are less apparent when using differing survey types. For example, a study comparing an on-site survey with a household survey of what was believed to be the same population found differences in angling welfare across the two groups, indicating that these sampling types inherently targeted two different angler types (Hynes et al. 2006).

Increasing human dimensions understanding

The beliefs, attitudes, and behaviors of anglers are fundamental drivers of recreational fishery dynamics (Fulton et al. 2011; Ward et al. 2016), but current creel surveys sometimes pass up opportunities to quantify them. Increased focus on human dimensions in creel surveys could greatly improve understanding of processes that are central to fishery dynamics. Creel surveys predominantly focus on harvest, catch, and effort, but do not specifically target the underlying drivers of these variables (e.g., angler attitudes and behaviors). Human dimensions are integral for the development of theory and management strategies in SES.

One area in fisheries science that has been identified as important for research is angler decision making, likely a key aspect to synthesizing SES functioning (Solomon et al. 2020). Adopting a social role and internalized identity as an angler has been found to influence an individual's environmental stewardship behaviors (Landon et al. 2018). A better understanding of angler heterogeneity, including centrality-to-lifestyle and angler identity could help managers to better understand trends in participation and conservation-related initiatives related to recreational fishing (Landon et al. 2018). Increased understanding of the angler population can lead to positive fishery outcomes, however, in many fisheries, this information is missing. Fisheries managers in the Great Lakes region, for instance, have indicated a need for increased information on economic valuation, beliefs and attitudes, and angler behaviors (Heck et al. 2016). Many questions involving angler dynamics could potentially be answered through the careful synthesis of existing creel data. Although these data have been used to estimate variables such as effort across the landscape (Chizinski et al. 2014), there is still opportunity within these data to test for trends and relationships in angler behaviors, participation, target-species fidelity, demographics, equity, and accessibility issues within recreational fisheries.

One emerging critical need for fisheries managers is an increased understanding of catch-and-release practices in a fishery (e.g., Kaemingk et al. 2020). Some angler-intercept surveys do include a metric for catch-and-release that can be used to identify not only how many fish are released, but also to illuminate social trends in consumption. Catch-and-release practices have been linked to changing social norms regarding conservation attitudes (Oh and Ditton 2008; Sass and Shaw 2020), increased awareness of perceived consequences of harvest (Stensland et al. 2013), and perceptions of animal welfare and the extension of the moral domain encompassing fish as moral patients (Arlinghaus et al. 2007; Cooke and Sneddon 2007). The role of social norms, within recreational angling, however, has yet to be fully understood (Arlinghaus et al. 2007; Heberlein 2012). Increased catch-and-release practices are likely to decrease the abilities of managers to structure fish communities and can cause imbalances in multispecies fisheries using current management techniques (Miranda et al. 2017; Sass and Shaw 2020). Detailed information on the prevalence of catch-and-release practices are sparse in many North American fisheries (but see Gaeta et al. 2013; Nguyen et al. 2013; Gilbert and Sass 2016; Shaw et al. 2019; Sass and Shaw 2020). Integrating consumptive data with demographic trends can reveal trends in social norms, conservation orientation, and food security within different demographic groups. For example, urban anglers and anglers from lower income brackets tend to place a higher importance on catch and consumption (i.e., subsistence) than rural anglers from any income bracket (Burger 2002; Hutt and Neal 2010). Recent efforts have been made to increase fishing participation in urban areas (Balsman and Shoup 2008), but the extent of the urban-to-rural divide in fisheries participation, accessibility, and equity in opportunity is currently unknown.

Currently, understanding of angler attitudes and beliefs lag behind other aspects of recreational fisheries. Increasingly, the role that attitudes play in angler behavior is conceded, including driving responses to regulatory changes (Murphy et al. 2019), species preferences (Arterburn et al. 2002), catch-and-consumptive orientation (Anderson 2005), and specialization and site substitution (Oh et al. 2013). Here exists an opportunity to increase knowledge of angler behaviors by increasing the availability of human dimensions data that are explicitly linked with catch data. The addition of human dimensions questions to angler-intercept surveys would allow for direct linkages between attitude and behavior information and subsequent catch and effort for those angler groups.

How to get there (road forward)

As SES-oriented thinking becomes increasingly the norm in fisheries, a road map of necessary steps must be developed to integrate creel data in order to effectively manage fisheries. Recently, efforts have been made to catalog the most pressing questions in fisheries science (Holder et al., 2020). Although the field of fisheries is beginning to look forward to a new era of management, it is important to use resources from the past in order to inform future management. The path forward will necessitate using long-term creel-survey data in new and innovative ways, but will also necessitate changes to surveys as they are understood to focus on arising issues and challenges in the field. Efforts have been made in marine recreational fisheries to begin a "new era" of creel surveys, combining angler-intercept and phone surveys to understand fishing effort along the United States coastline (Opsomer and Breidt 2013). But, this is only the beginning. Inland recreational fisheries are poised to begin transitioning to SES-focused management goals, and restructuring creel surveys can accelerate this transition.

Opportunities to expand creel surveys to SES can only be realized through careful collaboration with anglers, stakeholders, managers, and researchers. The road forward necessitates inclusion of the following steps to integrate creel surveys into SES-focused management: (1) incorporating human dimensions questions; (2) standardization of available data; (3) increasing tools and trainings available to fisheries researchers; and (4) increasing data availability. These steps will need to be incorporated at multiple points within design, implementation, and analysis of future creel survey efforts (Figure 2).

Incorporating human dimensions questions

Managing fisheries through a SES lens requires the incorporation of the social dimensions of recreational anglers. Simple additions to angler-intercept surveys, in many cases, might increase the ability to explicitly link human dimensions with patterns of harvest. For example, postal codes (both of primary and secondary residences) of anglers can be used to assess a rough approximation of distance traveled, which can serve as a metric for an angler's willingness-to-pay for a fishing experience (Parsons 2003). This information can then be used in combination with other data gleaned from the creel survey to understand aspects of the economic value of that fishery (e.g., Melstrom and Lupi 2013). Further, postal codes can reveal general demographic trends (i.e., urban or rural) that can inform human dimensions understanding of these fishery systems. Asking questions regarding identity and centrality-to-lifestyle can reveal other trends in participation (Landon et al. 2018). These types of additions can be used to understand human dimensions beyond stated preferences typical of mail-in survey data, and also allow managers to understand direct, revealed preferences of anglers in a fishery. Additionally, a simple question such as "why did you choose this fishing site" could reveal patterns in angler-site choice. Although some research has been conducted to understand angler-site choice (e.g., Hunt et al. 2019), many of the factors used to model site choice are based on *a priori* estimations of what is considered important in site choice, and may be missing important nuance and tradeoffs in site choice that could reveal angler motivations.

Increasing the number of questions asked, or altering format of angler-intercept surveys (e.g., pre- and post-trip interviews), are changing how many surveys are conducted. Increasing the number and types of questions are likely to increase contact time – which in turn may decrease the total number of interviews. For some systems, such as those with limited access points, these limitations may be negligible; however, for some fisheries landscapes, there may not be a simple solution. Increasing the number of questions during angler-intercept surveys may also increase the need to collect personal data, resulting in decreased willingness-to-participate by anglers. Although it is commonly assumed that increasing question number and contact time will decrease participation, this is not necessarily the case. An experimental creel survey conducted over two summers in northern Wisconsin worked to incorporate metrics of angler satisfaction into the creel survey (Iwicki, unpublished) and found that even with increased contact time, there was still an angler response rate around 90%, a rate which is equal to, if not greater than, other angler-intercept survey response rates. Similarly high response rates have also been documented with increased number and intensity of questions for hunter surveys on public lands in Nebraska (Wszola et al. 2020).

Standardization of available data

To account for differences in the structure and use of creel surveys, careful measures must be taken to develop creel surveys that, while meeting the needs of the individual fishery, also have some measure of standardization that allows cross-system and cross-state comparisons. This is a delicate balance that can only be achieved through continual review of methodologies and collaboration across systems. Careful development of integrated creel surveys could provide fisheries management with rich data (social and ecological in form) that are an important key to adaptive management (McLain and Lee 1996). Further, incentives must be put in place that encourage the development and collaboration of angler interview data at a large scale. These different surveys and outputs offer a unique look into how fisheries management has changed over time and space to address the region-specific needs of each fishery. With careful research, much of the data contained in these surveys can be integrated to provide larger snapshots of fisheries across broader regions. Robust metadata and data-storage policies can increase the potential applications of data through increased ability to translate data across fishery systems.

Although collaborations across political boundaries exist, standardizing data sets could increase the likelihood of these data being used to answer management questions that span a larger spatial scale. Many fisheries design creel survey effort to focus on high-pressure systems, species-specific systems (e.g., lakes with walleye (*Sander vitreus*) fisheries), or systems that are frequented by non-local anglers. For example, some angler intercept surveys are designed to intercept anglers at popular boat launches (Robson and Jones 1989). High levels of effort are placed into survey design in order to minimize survey effort and bias and maximize fishing effort estimates (e.g., Deroba et al. 2007). This can result in sampling regimes that are highly system-specific. Some systems, such as the nearshore fishery in Western Perth, Australia, encompass such a large spatial range that an expanded aerial survey combined with cameras has been found to be the most effective sampling regime (Smallwood et al. 2012). Additionally, different sampling strata present across many surveys results in different estimations of harvest and effort when comparing different creel survey methodologies. Along the Missouri River in South Dakota, a combination of aerial and bus route creel surveys were conducted, with each method reporting differing estimates of overall angler effort within a single system (Soupir et al. 2006). Further, catch rate estimators used to project total catch within a fishery vary by fishery. This increases the complications involved in making comparisons across systems without tedious corrections being made for differing management resource allocation. This can be further confounded by avidity related bias in response (Barrett et al. 2017), resulting in skewed estimation of participation in some fisheries (Thomson 1991). Nevertheless, adoption of similar statistical methodologies of calculating catch from raw creel data can reduce bias within these estimates (e.g., Jones et al. 1995). Standardization, such as those being pursued by the CreelCat endeavor (USGS, 2020) across systems, can decrease the issues associated with sampling disparity.

Increasing tools and trainings available to fisheries researchers

Although much of the data that could illuminate SES dynamics exist, a barrier to their use is the availability to researchers for this explicit purpose. Increased trainings and workshops, for example at fisheries meetings or facilitated through other avenues, could provide those researchers that work with creel surveys the skills necessary for developing and analyzing survey data that can be applied to SES thinking. Tools include considerations ranging from database analysis to linking these data to alternative data (e.g., demographic data, environmental data; Table 1). Needs for this endeavor include tools designed to work within the confines of unorganized data and large datasets. Statistical tools exist, but specialization of these tools in an open access program (such as R statistical environment [R Core Team 2017]) could increase accessibility.

Training in SES thinking at different levels of management can increase the use and effectiveness of angler-intercept and mail-in surveys to understand social and human dimensions of recreational fisheries that are often overlooked. Training should be extended beyond data analysis to active design and implementation of surveys. Workshops that span regional creel efforts could increase regional collaboration and standardization of creel surveys (as appropriate), and also help survey design to be more robust and encompass multiple aspects of broader SES.

Increasing data availability and collaborative efforts

A key component of synthesizing data is ensuring that the data collected are available for use, and that availability is extended to not only direct management action, but also to collaborative efforts that span across different recreational fisheries. Collaboration is one of the most important steps forward that can facilitate the use of creel surveys in SES research. Current efforts exist to create a national database of creel survey data (CreelCat; USGS, 2020), and serve as a step in increasing the use of these data in SES. For large scale, spatio-temporal analysis of creel data, collaboration across multiple entities will be essential, including agencies that conduct creel surveys, but also economists, social scientists, geographers, and demographers (among others). This will allow the accurate and holistic incorporation of SES thinking into fisheries science. Integration of demographic data from the U.S. Census can provide key insights into how socio-economic factors relate to participation in recreational angling across the United States. Such key research, however, will necessitate collaboration across traditional disciplinary boundaries. Although fisheries have had a long history of interdisciplinarity (especially across biology, ecology, and economics), the incorporation of fields beyond those traditionally associated with fisheries, such as human ecology, sociology, and demography, are likely to increase understanding of the intricacies of these systems.

Conclusions

Although developing new creel surveys is an arduous venture, updating existing surveys can provide key human dimensions information to increase their use in research and their effectiveness in management. Careful development of new creel surveys can improve human dimensions and SES knowledge of these systems in ways that further enable managers to use tools such as ecosystem-based fisheries management (Gray and Jordan 2010). Updating angler intercept surveys, while being highly beneficial for ongoing and future fisheries research, will have to be done carefully in order to preserve existing long-term regional data sets that are essential to regional management. Although surveys must by necessity be system specific, some types of questions can transcend those systems and can provide information that can be used to analyze across systems. Changing creel surveys is likely to be a long, slow process due to the generally limited budgets of state management agencies, in addition to the locally specific methods used by current surveys. The benefits of transforming these data to datasets that integrate social and ecological characteristics of the fishery will allow for adaptive management (Camp et al. 2020), something that is becoming more and more important as the planet faces unprecedented change.

There are still a variety of questions and issues associated with integration of traditional angler-intercept creel surveys and SES research. Many of the issues that arise will need to be dealt with on a case-by-case basis. Questions arise on the ability to integrate human dimensions questions in creel surveys, while maintaining the basic angler-intercept structure. Barriers including response bias, importance of certain questions, and interview length will make this task challenging. Although development of creel surveys that integrate social and ecological questions will take time, ultimately the ability to manage recreational fisheries from a SES-view will increase the resilience of these systems (Folke 2006; Pope et al. 2014; Arlinghaus et al. 2017; Carpenter et al. 2017). This will allow fisheries managers to not only assess the ecological status of fisheries, but also to understand more about the users of the system. Ultimately, adopting a SES approach to creel surveys will address basic fisheries management objectives as well as improve the sustainability of these important resources and the well-being of anglers.

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ORCID

Chelsey L. Nieman http://orcid.org/0000-0002-7035-6040
Abigail J. Lynch http://orcid.org/0000-0001-8449-8392

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