# Alaska fishers attest to climate change impacts in discourse on resource management under marine heatwaves

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## Keywords

Climate change, Alaska, fisheries, well-being, marine heatwave, public comments

## Abstract

Impacts of climate change on fisheries are intensifying, especially in northern latitudes, yet pathways to adaptation remain unclear. We analyze the vulnerabilities and adaptations of fisheries participants in discourse represented by public comments on state fisheries management in the Gulf of Alaska, where extreme climate events impact diverse and robust cultures of fisheries participation. With 18,422 comments by 5,715 commenters from 2010 through 2021, we parse discourse through content analysis in a well-being framework and capture trends in principal component analysis. Climate change becomes more prominent in discourse with the impacts of extreme marine heatwaves. However, attribution and cognitive dissonance processes result in entrenchment of polarizing viewpoints between user groups on fisheries allocations and enhancements. Yet some adaptation pathways emerge that bridge fishing identities with empowered conservation. By expanding approaches to examining public discourse captured in big qualitative data, these methods and findings can help inform fisheries climate adaptation policy.

# 1. Introduction

The impacts of climate change on marine ecosystems are intensifying (Collins et al., 2019; Pershing et al., 2018), including poleward species shifts (Melbourne-Thomas et al., 2022), harmful algal blooms (Brown et al., 2020), and marine mammal die-offs (Gulland et al., 2022), among others. Despite increasing evidence and predictions of severe climate impacts on coastal communities, adaptation pathways remain unclear (Himes-Cornell et al., 2018; Miller et al., 2018; Pershing et al., 2018). Initiatives for resilience in coastal communities often focus on a subset of climate-driven hazards or exclude climate change altogether (Almutairi et al., 2020; Lalancette and Charles, 2022). Research increasingly points to the necessity of bridging local knowledge and value systems with climate science and attribution as critical for developing adaptive capacity that is appropriately contextualized and thereby sustainable (Brown et al., 2019; Gianelli et al., 2021; Lau et al., 2021).

Across the world, coastal community residents rely on the health of marine ecosystems to harvest fish for subsistence, livelihood, cultural practices, and numerous other dimensions of well-being (Breslow et al., 2016; Szymkowiak and Kasperski, 2021). Fisheries participants experience climate change on complex, interrelated dimensions of social-ecological systems, from changes in participation in resource and non-resource livelihoods to changes in ecosystems and the direct impacts of natural hazards (Badjeck et al., 2010; Dubik et al., 2019; Peterson et al., 2017; Thomas et al., 2019). These complexities create challenges for participants in attributing environmental changes to climate change, making adaptation difficult to conceptualize (Maltby et al., 2021; Van Putten et al., 2016; Zhang et al., 2012). The challenge of understanding fisheries participants' discourse on vulnerabilities and adaptations to social and environmental change requires a comprehensive approach to understanding climate and non-climate themes (McIlgorm et al., 2010; Sumby et al., 2021). We examine fisheries discourse in the Gulf of Alaska in response to climate-driven changes that are undermining the health of the marine ecosystem and its iconic fisheries (Litzow et al., 2018; Oke et al., 2020).

Fisheries management in the United States and elsewhere has institutionalized public comment processes in discourse for decision-making. Fisheries participants contributing proposals and comments to these processes offer diverse perspectives rooted in local experiences of social and environmental change. To date, research on climate change discourse within fisheries management institutions has reflected the challenges of capturing the breadth of vulnerabilities and adaptations (Lindegren and Brander, 2018; Miller et al., 2018; Pinsky et al., 2021). Dubik et al. (2019) track fishery management narratives over climate-driven shifts in the distribution of northern flounder off the northeast United States. Whitney et al. (2020) examine perceptions of alternative climate adaptation actions in coastal First Nations of British Columbia, Canada. McCay et al. (2011) consider decision processes for climate-stressed Atlantic surfclam fisheries. Finally, Spijkers and Boonstra (2017) trace social conflict following a climate-driven shift in species distribution for northeast Atlantic mackerel. These studies demonstrate the value of mixed methods in grappling with impacts of climate change in complex social-ecological systems, and the importance of discourse for resource management under accelerating change.

In Alaska, robust fisheries, fishing cultures, and dependence on fishing intersect with management processes that have a long-standing public comment process. In 2019, commercial fisheries off Alaska produced 5.7 billion pounds of seafood worth $2.0 billion (USD) -- more than the rest of the United States -- and employed over 31,000 fishers (Alaska Seafood Marketing Institute, 2022). In addition to being the largest private sector employer in Alaska, commercial fishing provides critical livelihood opportunities for isolated coastal communities throughout the state, as well as food security, cultural transmission, and social connectivity, among many well-being dimensions (Szymkowiak and Kasperski, 2021). Despite the tremendous and diverse values that are derived from Alaska fisheries, due to a combination of management and sociocultural changes and more recently climate driven impacts,  access, opportunities, and local income derived from these fisheries have declined (Oke et al., 2020; Ringer et al., 2018; Szymkowiak and Kasperski, 2021).

Climate change impacts have been evident in Alaska's marine ecosystems for some time (Pershing et al., 2018), for example in declining salmon body sizes (Oke et al., 2020) and changes in fundamental salmon ecologies (Litzow et al., 2018). From 2014 through 2016 and in 2019, marine heatwaves struck the Gulf of Alaska, elevating temperatures throughout the water column with profound impacts on ecosystems and fisheries (Batten et al., 2016; Zador et al., 2019, 2015, 2014). These impacts have persisted, testing the resilience of social-ecological systems across the region (Cheung and Frölicher, 2020; Suryan et al., 2021). With marine heatwaves predicted to increase under climate change with corresponding challenges to resilience in ecosystems and fisheries (Litzow et al., 2021), public discourse among fisheries participants impacted by climate-driven heatwaves offers critical opportunities to reveal experiences of climate change and extreme events.

We demonstrate a mixed qualitative and quantitative approach to understanding discourse on climate change in Alaska fisheries over 18,422 comments made by 5,715 commenters to state fisheries managers from 2010 through 2021. We focus on comments specific to state fisheries on the Gulf of Alaska, where most Alaska commercial fisheries are prosecuted, capturing unique diversities of fisheries, participants, and climate change impacts across the region. We first approach comments through content analysis, identifying concepts and iterating through associated terms. We next use principal component analysis to characterize the role of climate change in discourse. As people have experienced the cumulative impacts of heatwaves, climate change discourse has become more prominent. We conclude with an analysis of public comments and discuss the implications of trends in discourse for fisheries participants, managers, and researchers in the Gulf of Alaska under intensifying and uncertain impacts of climate change. We build on the mixed methods approach using big qualitative data (Davidson et al., 2019) and principal component analysis to assess climate adaptation in fisheries systems (Seara et al., 2016). The methods demonstrated in this work can be applied to similar case studies where big qualitative data requires quantitative methods for exploration.

## 1.1 The Gulf of Alaska fisheries system

The three nautical mile (nm) line from the coastline demarcates the boundary between state (0-3 nm) and federal (3-200 nm) fisheries jurisdictions off Alaska. Gulf of Alaska state commercial fisheries consist of Pacific salmon, including all five species, as well as groundfish (sablefish, Pacific cod, rockfish, and lingcod), crab (Dungeness, Tanner, king), other invertebrates, and herring. These fisheries are managed with a mixture of limited and open access permits, gear and vessel length restrictions, seasonal closures, and harvest limits. Subsistence, personal use, and sport permits are available for these species as well, subject to residency, harvest, gear, and season limits.

State fisheries off Alaska are managed by the Alaska Board of Fisheries ("the Board"), which consists of seven members appointed by the governor (Alaska Department of Fish and Game, 2022). The Board solicits local, public participation in four to five meetings per year held in regional hubs throughout the state. Comments from the public inform regulations and resource allocations issued by the Board for implementation by the Alaska Department of Fish and Game (ADF&G). The public includes fisheries participants from all groups – commercial, subsistence, personal use, and sport – as well as tribes, municipal leaders, environmental organizations, hatchery associations, fish processors, and ADF&G. Issues before the Board are complex, involving multiple fisheries, target and non-target species, multiple groups of participants, and social and environmental concerns beyond fisheries – including climate change.

Public comments to the Board respond to proposed changes in fisheries regulations, which are taken on a three-year cycle by region by fishery (finfish, Pacific cod, and shellfish) and through annual statewide meetings, although fisheries and sub-regions have been differentially grouped over time. The Board also meets to conduct administrative and regulatory business during regular “work” meetings and “special” meetings, joint protocol meetings with the federal fisheries management body on areas of mutual interest, emergency meetings in response to fishery downturns or proposed closures, and meetings focused on stock enhancement through the hatcheries -- a system the Board manages indirectly through hatchery release and harvest regulations. All types of Board meetings were disrupted in 2020 and 2021 by the COVID-19 pandemic, which prompted meetings on alternative schedules and in different formats (Haight, 2020). Across meetings, public comments range from highly individualized remarks to duplicative comments signed by different individuals in mass comment campaigns. Comments often involve allocation, since regulatory changes to fisheries frequently imply catch, season, area, gear and other adjustments that result in fish moving from one user group to another. Some comments also include full scientific papers or reports as support.

The public participation process within the Board has been examined recently through work focusing on the historical outcomes of the proposals themselves, relative to characteristics of the proposer (Krupa et al., 2020, 2018). This work points to substantial differences in success rates for proposals with managers (the Board and ADF&G) accounting for the vast majority of successful proposals relative to other stakeholders - individuals, tribes, fishing associations, etc. More recently, Harrison and Gould (2022) examined public comments to a 2019 Board meeting on hatcheries coupled with semi-structured interviews with fisheries stakeholders to identify the themes that underlie tensions over hatcheries in Alaska - the results of which illuminate hatchery discourse in our analysis and are discussed further below. Our analysis contributes to this growing body of literature on public participation processes in Alaska fisheries through the use of big qualitative data methods to examine the full corpus of publicly available, digitized comments to the Board.

# 2. Materials and Methods

## 2.1. Data

We analyze comments made to the Board from 2010 through 2021, focusing on the period featuring complete and consistent comments across meetings. We further focus analysis on the Gulf of Alaska, eliminating meetings targeting fisheries in the Bering Sea. This focus captures several features of the Gulf of Alaska: diverse commercial fisheries and user groups, large-scale local participation in state fisheries, and environmental changes that are homogenous by comparison to the Bering Sea. Furthermore, most Board meetings and regulations target Gulf fisheries. Figure 1 demonstrates the distribution of Board meetings used in our analysis across Gulf of Alaska state fishery regions, as well as the number of statewide, hatchery, emergency, and other meetings in our analysis.

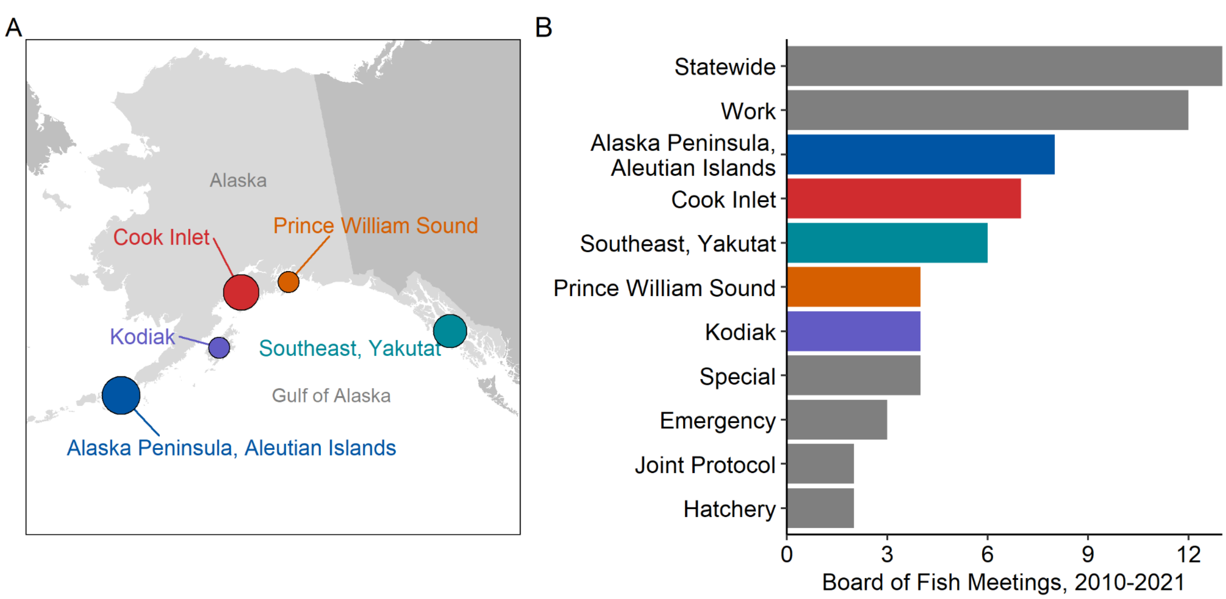


**Figure 1.** Alaska Board of Fisheries meetings with public comments relating to fisheries on the Gulf of Alaska, summarized to regional aggregations and categories of meetings for 2010-2021.

Regions match fisheries management areas reflected in Board meetings as well as aggregations intended to simplify the figure: Alaska Peninsula/Aleutian Islands (Alaska Peninsula, Aleutian Islands, Chignik); Cook Inlet (Lower and Upper Cook Inlet); Kodiak (Kodiak); Prince William Sound (Prince William Sound, Upper Copper River, Upper Susitna River); Southeast/Yakutat (Southeast and Yakutat, Tsiu River).

The dataset consists of 18,422 comments made by 5,715 commenters, consisting primarily of commercial fisheries participants, with comments from other fisheries user groups (subsistence, personal use, and sport) as well as other stakeholder groups - tribes, municipal leaders, environmental organizations, fish processors, hatchery associations, and ADF&G. Many of these individuals or organizations provide multiple remarks to the Board over the time series. We examine all comments and their contents, inclusive of scientific papers and mass comment campaigns, to avoid the potential introduction of researcher bias through value judgments on exclusion of some comments. Figure 2 demonstrates the increase of commenters and total pages of comments over the time series. The figure also points to the cyclical nature of comments, with higher comment counts associated with finfish meetings on potential salmon regulations that would affect large user groups. All comments used in this analysis are available online (ADF&G, 2022).

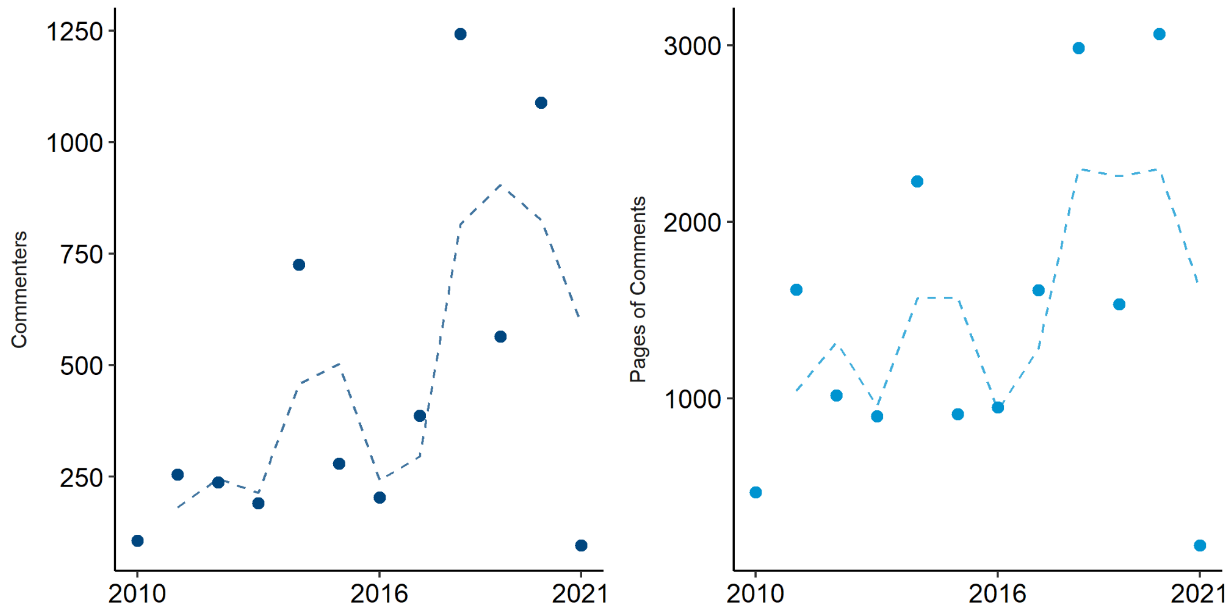


**Figure 2.** Counts of commenters and pages of comments for Board of Fisheries meetings each year from 2010 through 2021. The two-year moving average appears in dashed lines.

## 2.2. Methods

### 2.2.1. Processing public comments for analysis

We process public comments in Adobe Acrobat using the optical character recognition function to create a searchable layer of text. We used a content analysis approach to identify key concepts across the time series of data (Table 1). These concepts include science (processes and outcomes), management tools and frameworks, fisheries (species and gear groups), stressors (environmental, human-driven, exogenous, and cyclical), and the biological, individual and social outcomes of these stressors and fisheries participation. Because the relationships between fisheries, stressors and individual and social outcomes were described in terms of dimensions of human welfare, we applied a well-being framework (Breslow et al., 2016) to categorize these connections into dimensions of well-being. These well-being dimensions include fisheries access and allocations; sustainability and resilience; connection to self, place, and others; livelihood and economy; and health and safety.

We then identified the terms that were frequently associated with each concept across the time series of comments. MaxQDA's dictionary function allows for the creation of a list of key categories and the search terms that will be used to identify the use of those categories throughout the text, which is called a dictionary in the software. We developed a dictionary for our analysis through an iterative process wherein we tested the efficacy of terms to identify categories and refined the dictionary to ensure consistent use of terms across comments and time for a given category. MaxQDA provides a matrix output of frequencies of categories within the dictionary by document, providing an output that is suitable for examination using principal component analysis (PCA).

**Table 1.** Concepts in Board comments with associated categories and terms.

| Concept | Categories | Lemmatized Terms |
|---|---|---|
| Science | science | science, biology, data, analysis, method, research, monitor, survey, evidence, information, measure, evaluate, enumerate, parameter, model, sample, fact, literature, methods-specific terms (mark-recapture, genetic stock identification, management strategy evaluation) |
| Management | caution and reduction | caution, conservation, restrict, limit, cap, risk avoidance and reduction, achieving and controlling escapement, stocks of concern |
| | area management | protected or management areas, area closures, sanctuary, critical habitat, marine mammal areas, boundary extension/modification, Steller sea lion areas |
| | limited access privilege programs (LAPPs) | catch or quota share, rationalization, limited entry or access |
| | hatchery production | hatchery production, enhancement |
| Fishery | groundfish | halibut, sablefish, rockfish, ling cod, pacific cod |
| | herring | herring |
| | shellfish | crab, shrimp, squid, mussel, octopus, abalone, clam, oyster |
| | gear | gear, seine, gillnet, setnet, dipnet, troll, trawl, longline, jig, pot |
| | subsistence | subsistence |
| | commercial | commercial |
| | personal use | personal use |
| | recreational | recreation, charter, sport |
| | salmon | salmon, chinook, coho, sockeye, chum, pink, as well as colloquial names for the species (reds, silvers, dogs, humpies, kings) |
| Stressors | overfishing and overcrowding | over (fish, crowd, harvest), deplete, concentrate, pressure |
| | climate change | climate (change, event, regime, data, conditions, variation, induced, forcing, phenomenon, impact, effect, based, relate), warming, sea/ocean/stream temperature, blob, heatwave, ocean acidification, and specific climate impacts (algal blooms, droughts, landslides, storms, PSP events) |
| | bycatch | bycatch |

| | | |
|---|---|---|
| | cycles and shifts | cyclic, Pacific Decadal Oscillation, regime shift, North Pacific regime, climate pattern |
| | hatchery competition | hatchery competition, hatchery dump, carrying capacity, stray, industrial hatchery, displace wild salmon, feeding contest |
| | markets | markets, prices |
| | other stressors | Exxon Valdez oil spill, pollution, habitat loss, whale depredation, invasive, COVID |
| Well-Being | fisheries access and allocation | allocate, apportion, access, consolidation, equal, justice, fish grab |
| | sustainability and resilience | sustain, steward, resilience, vulnerability, adapt, stability, opportunity, innovate, healthy stocks, transform, structural change |
| | connection to self, place, and others | way of life, identity, place-based, self, heritage, family, community, social, village, group, culture, spirit, custom, tradition, LEK, TEK, multi-generational |
| | livelihood and economy | livelihood, economy, living, job, employment, financial, revenues, taxes |
| | health and safety | mental /physical health, safety, food, hazard, risk to life |
| Biological Outcomes | stock decline | decline, decrease, deplete, diminish, depress, low abundance, crash, collapse, low (run, return, GHL, TAC) |
| | fish size and quality | fish size/weight, length and weight-at-age, virus, parasite, lice, disease, chalky, fish quality |

### 2.2.2. Analyzing public comments over principal components

With data to capture themes in comments for each month, we use principal components analysis (PCA) to explore variance across months. PCA finds linear combinations (principal components) of variables -- henceforth “categories” to follow terms applied in qualitative analysis -- so that each explains a distinct proportion of total variance (Bro and Smilde, 2014). Interpretation of categories and data over principal components offers multiple advantages: projecting comments onto principal component space reduces the data to fewer dimensions, eliminates correlation among those dimensions to capture distinct trends, and reveals relationships among categories. We use results of PCA to select a critical subset of categories, to examine the effects of time and an extreme climate event on discourse in comments, and to describe the role of climate change in comments.

Steps to filter, transform, reduce, and interpret data precede the results of PCA. We conduct data preparation and PCA with R (R Core Team, 2021), RStudio (RStudio Team, 2020), and Tidyverse packages (Wickham et al., 2019). We preserve outlier months in the data -- those with counts of terms for most categories that are several times those of other months -- because their high counts of terms reflect environmental and social dynamics critical to understanding comments discourse. We center and scale categories so that each has a mean of zero and a standard deviation of one and calculate covariances. We conduct PCA on the resulting matrix and select a useful subset of principal components by their contributions to total variance visualized in scree plots (Cattell, 1966), first for the full dataset and second for the subset of categories created in the following steps. We project data and categories to principal component space in distance biplots (Gabriel, 1971) to visualize the loadings of categories on the subset of principal components, again for the full dataset and the subset of categories presented in Results. We reduce the data through iterative eliminations of categories with the lowest loadings on the subset of principal components and, finding minimal change in the remaining categories' loadings, arrive at a subset of 13 categories from the initial 28. We examine and discuss the distribution of data for this subset over principal component space with reference to an extreme climate event and climate change terms' role in discourse. We inform this interpretation of variance in the data with an examination of raw frequencies of the iterated subset of categories over the time series.

### 2.2.3. Examining climate discourse in public comments

The final step in the analysis was an examination of the discourse specific to climate change in the public comments, with identification on the search terms for climate change in Table 1. We applied a grounded theory approach (Glaser and Strauss, 1967) to understand the context of climate change comments and their relationships to the central concepts and categories identified in Table 1. We build on the PCA by examining the intersections of climate discourse with management recommendations, science interpretations, and well-being implications.

Grounded theory is particularly suited for examining climate discourse by fisheries participants because of how complex social-ecological systems intersect with climate impacts and make attribution difficult. The inductive nature of grounded theory provides for the discovery of social processes without *a priori* assumptions of theoretical frameworks (Charmaz, 2008). This is especially important due to not only the complexities of intersecting issues and systems in fisheries discourse but also the emergent nature of climate impacts (Fløttum and Gjerstad, 2017).

# 3. Results

## 3.1. Content analysis of public comments

Issues facing the Board are complex, involving multiple fisheries, target and non-target species, multiple groups of participants, and social and environmental concerns beyond fisheries. In turn, comments to the Board reflect this mosaic of social-ecological system issues and challenges. Comments most often begin with self-introductions positioning participants within user groups (subsistence, commercial, personal use, recreational) and fisheries (species and gears). Comments respond to proposals before the Board, noting their support or opposition. Issues involving fisheries access and allocation tend to elicit more comments, reflecting conflicts between user groups and differences in participants' experiences of social-ecological systems change.

Figure 3 illustrates frequencies of terms in concepts that emerged from the qualitative analysis. From 2010 through 2021, there is substantial variation in participants' incorporation of concepts and categories (groups of concepts) in comments on proposed regulations. Most categories are absent from multiple meetings across the time series. Comments speak to biological changes in terms of harvest, returns, and runs, and to corresponding changes in allocations and regulations. These allocation discussions are evident in Figure 3 with increasing frequencies of terms that communicate differential impacts of social-ecological change across user and gear groups and across areas, districts, and river systems. Participants incorporate language on conservation and escapement within comments that advocate for redistributions of fish via closures, limitations, gear specifications, and redistribution between target and non-target fisheries.

The importance of salmon is prominent in the greater relative frequencies of salmon terms shown in Figure 3. Salmon comments often relay allocative conflicts between user groups, which include advocating for regulatory changes that enhance one's opportunities at the cost of another. This discourse includes management of salmon released from hatcheries to enhance fisheries. Comments focused on hatcheries often polarize around stock dependence and associated concerns over hatchery production and effects on wild stocks. Some participants discuss hatcheries in relation to their potential adverse impacts through competition between wild and hatchery salmon. Other participants discuss the role of hatcheries in stabilizing harvests and economic opportunities.

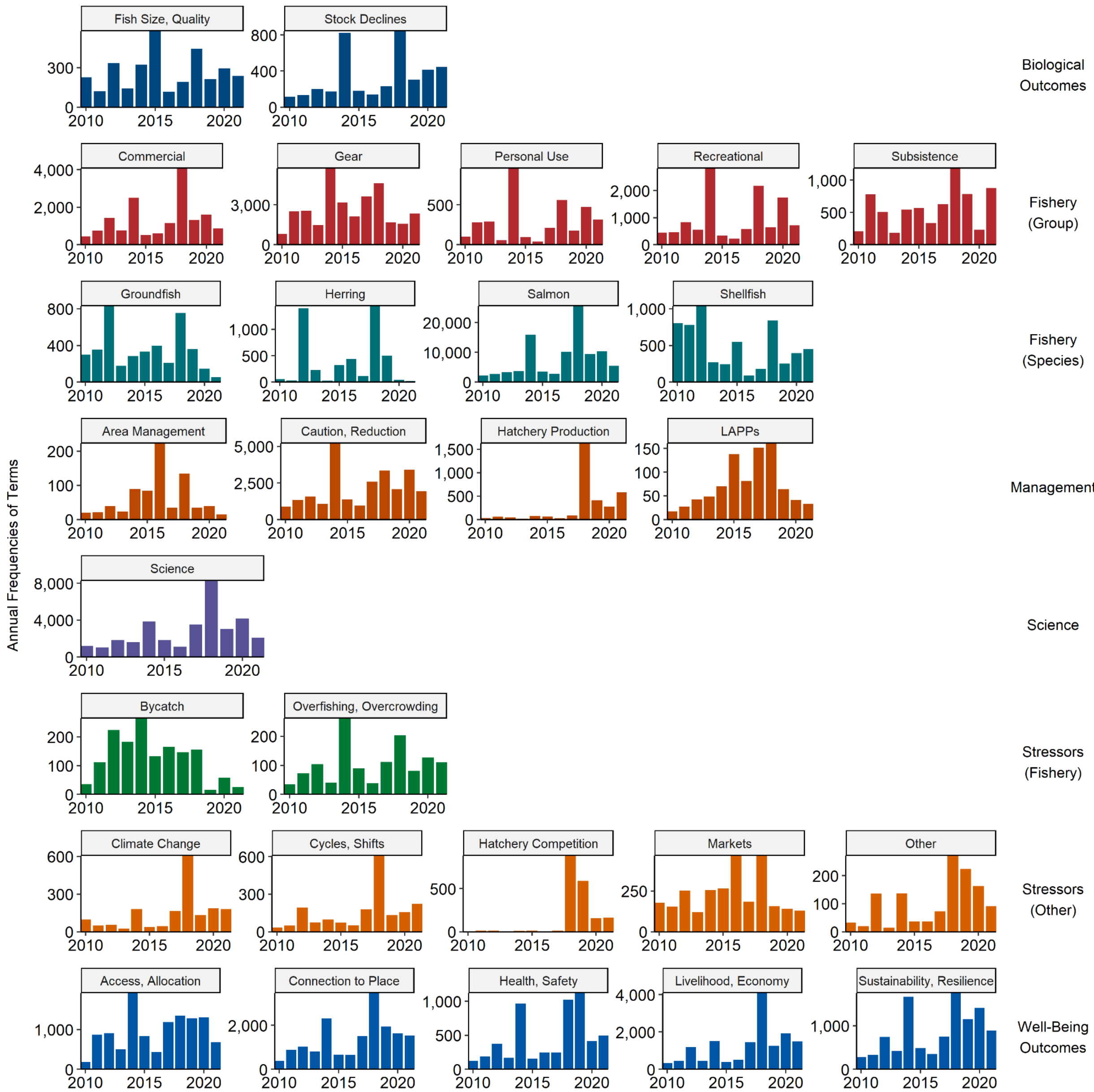


**Figure 3.** Annual frequencies of terms across comments by categories and concepts.

## 3.2. Qualitative analysis of climate discourse

The emergence of climate change themes in comments follows a clear trend in the time series, with sporadic references to climate terms until the impacts of an extreme marine heatwave beginning in 2014 (Figure 4).

majority of 2018 climate comments were in response to petitions for emergency regulations to close a commercial salmon fishery and to limit hatchery production of pink salmon -- both, as indicated in the comments themselves, in response to salmon downturns that resulted in fishery disasters. There was also a surge in climate comments in 2018 associated with the regular triennial meeting on Pacific cod fisheries, which were also under a federal disaster declaration following the heatwave. In 2019 and 2020, references to climate change were still more frequent than in 2010-2014, but the recurrence of heatwave conditions in 2019 did not prompt a clear spike as in 2018. This could be a result of lags as well as the COVID-19 pandemic altering stakeholders' access to and participation in Board processes. Although the co-occurrence of social impacts related to the 2019 marine heatwave and the COVID-19 pandemic complicates analysis, clear patterns emerge across the data.

Throughout the time series, climate discourse in public comments weaves themes that manifest in relationships among categories of terms -- cycles and shifts, hatcheries, science, salmon, and livelihood/economy. Comments speak to climate change as an existential crisis that stresses marine ecosystems in unpredictable and novel ways. Climate change and other climate cycles and shifts, including the Pacific Decadal Oscillation and marine regime shifts, intertwine in comments. Even for those who allude to a lack of human capacity to alter climate change, global warming is a "forcing function on a grand scale."

Climate discourse focuses on salmon fisheries, including impacts that have left salmon runs less sustainable and less predictable. In particular, comments include discussions of the role of warming waters in salmon fisheries through accelerating metabolism, diminishing food supplies, smaller runs, changes in migration and distribution, and disturbances to the biennial patterns of pink salmon returns. Fisheries participants discuss the adverse impacts of intensifying changes in precipitation -- extreme droughts and rainfall events -- that undermine spawning events and salmon fry survival.

Climate impacts on salmon have tremendous well-being implications on Alaskans that are manifest in the comments. Unpredictable and diminishing runs of smaller fish limit livelihood opportunities, undermine food security, and reduce recreational opportunities for Alaskans, disentangling them from a way of life that has existed in the region for thousands of years. Concerns about negative impacts of climate change on salmon in comments are associated with calls for precautionary measures and protection of resources. However, those terms co-occur with requests for seasonal, gear, or catch restrictions, which drive conflict between groups of participants. Opposition is justified in the discourse by direct revenue losses in commercial fisheries or indirect losses in recreational fisheries supporting tourism. Thus in the face of dwindling salmon resources, allocative battles become even more pronounced but are often disguised, potentially to fisheries participants themselves, by discourse about greater caution and protection. For some, this manifests in discourse that downplays the impacts of climate change relative to impacts of other groups of participants in salmon fisheries. These participants again recommend limitations on harvest for other groups -- essentially a reallocation of dwindling resources.

> “I believe that Area M has irresponsibly been harvesting anything that comes into their reach and it's now starting to show the consequences . . . I realize that the unusual warm weather we have been getting does play a big part in all of this, but I don’t want it to be a convenient scapegoat.”

Comments also relate impacts of climate change to impacts of hatcheries on salmon fisheries. Discourse about hatcheries increases in relation to climate change over time, along with increasing polarization on the impacts of hatcheries. For one contingent, the need for hatcheries and the economic stability they provide is greater with an uncertain climate. For the other, climate change exacerbates issues around carrying capacity and competition from hatchery fish on wild stocks.

> “The Gulf of Alaska is under significant stress, from climate change, ocean acidification, and warm water events such as the Blob, and the Blob 2.0 . . . Continually releasing

larger and larger numbers of pink and chum salmon fry into an already stressed marine environment increases the level of competition among all salmon in the Gulf of Alaska."

Following marine heatwaves, comments incorporating climate change discourse also include more frequent references to the role of science in management. In the face of climate uncertainty, fisheries participants discuss the necessity of deferring to science in decision making, using "best available science," providing for monitoring and data collection in management schemes, and expanding scientific processes to include other knowledge systems like traditional ecological knowledge. In the public comments, the topic of science is often used in climate discourse to advocate for specific management regimes that strategically displace some users. Discussion of science in the comments intersects with calls for precautionary management in hatchery production for those who rely on wild stocks; whereas those who rely on hatchery produced salmon defer to the science of state biologists who determine hatchery production.

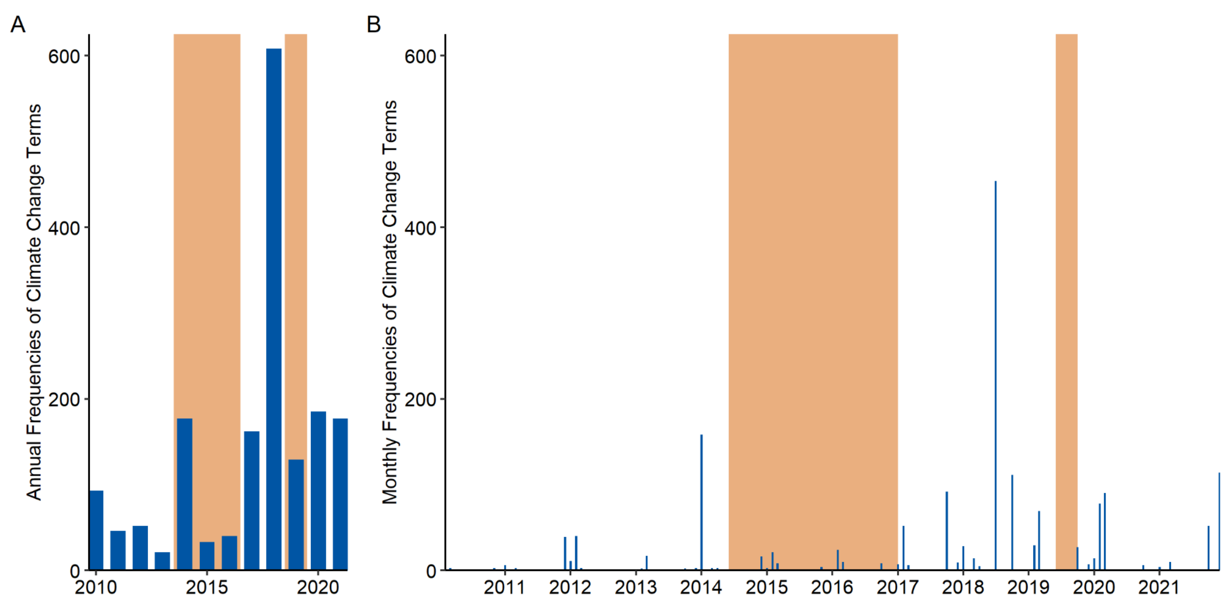


**Figure 4**. Frequencies of climate change terms in each year (A) and month (B) from 2010 through 2021. Shading illustrates marine heatwaves in the Gulf of Alaska (Barbeaux, 2021).

### 3.3. Principal component analysis

Principal component analysis (PCA) underscores the increasing importance of climate change in fisheries discourse and suggests relationships among frequencies of terms across the categories defined in Table 1. We present results for an iterated subset of categories on the first two principal components, which together account for 85% of total variance. Complete results for both the initial and iterated sets of categories appear in Appendix A, including diagnostic scree plots and tabulated loadings. Loadings indicate the contribution of categories to the total variance explained by a principal component and correlations of categories within principal component space. Positions of months in principal component space indicate commonalities and differences between months with reference to categories. Figure 5 illustrates both loadings of categories and positions of months over principal component space, enabling interpretation of categories' correlations and comparison of months over time and in relation to categories' loadings.

On the first principal component (PC1) -- the horizontal axis of Figure 5 -- months' positions follow the sum of comments over categories. This suggests PC1 is capturing variance in the number and length of comments across meetings in each month without a clear change over time. Outliers on PC1, in particular the months of January 2014 and July 2018 shown at the extreme right of Figure 5, are distinguished by higher frequencies of terms. We retain these outlier months despite their outsize effect on results because their values are both non-random, reflecting critical pre- and post-heatwave meetings on management of salmon fisheries, and consistent with the interpretation of other months' distribution. Categories with greater loadings on PC1 -- those shown by arrows extending further on the horizontal dimension of Figure 5 -- contribute more to variance explained by PC1. Those include Livelihood, Economy; Science; Salmon; Stock Decline; and Sustainability, Resilience. Those categories are then the most informative for understanding what drives greater total frequencies of terms for outlying months of Board of Fisheries comments.

On the second principal component (PC2) -- the vertical axis of Figure 5 -- months' positions fall into earlier and later groups: 2010-2016 and 2017-2021. While this separation could be an effect of unobserved changes over time, the latter period follows an extreme and persistent heatwave in the Gulf of Alaska that drove broad environmental changes with short- and long-term effects on fisheries and their participants. Categories with greater loadings on PC2 -- those shown by arrows extending further on the vertical axis of Figure 5 -- contribute more to the variance explained by PC2 and to the associated shift in fisheries discourse following the 2014-2016 heatwave. Those include Hatchery Production; Hatchery Competition; Cycles, Shifts; Climate Change; Overfishing, Overcrowding; Caution, Reduction; Access, Allocation; and Bycatch. PC2 reveals that these categories, and corresponding discourse in public comments, explain the separation of months from 2010-2016 and 2017-2021.

Categories' loadings -- the relative lengths and directions of categories' arrows in Figure 5 -- indicate the direction and magnitude of categories' effects on each principal component, suggesting two key groups of categories. First, several categories are correlated with Climate Change, including Hatchery Production; Hatchery Competition; Cycles, Shifts; Climate Change; Livelihood, Economy; Science; and Salmon. While most correlations between categories in this group are small, some suggest sub-groups of related categories. These capture climate change and related topics, which together contribute to the separation of months from 2010-2016 and 2017-2021 in the positive direction on PC2. Second, several categories are uncorrelated or less correlated with Climate Change, including Stock Decline; Sustainability, Resilience; Overfishing, Overcrowding; Caution, Reduction; Access, Allocation; and Bycatch. These represent topics less related to climate change, and drive separation in the opposite and negative direction on PC2. While loadings for both groups are similar on PC1, their separation on PC2 indicates less or no correlation, so that the separation of months into earlier and later periods follows uncorrelated changes in frequencies of terms and not a decrease in frequencies of terms within either group. Altogether, PCA captures the shifting roles of different topics in public comments from 2010-2014 to 2017-2021. In particular, PCA demonstrates that discourse has focused more on hatcheries, cycles and shifts, and climate change since the heatwave, while offering the caveat that outlying months pre- and post-heatwave feature more discussion of livelihoods, science, and salmon.

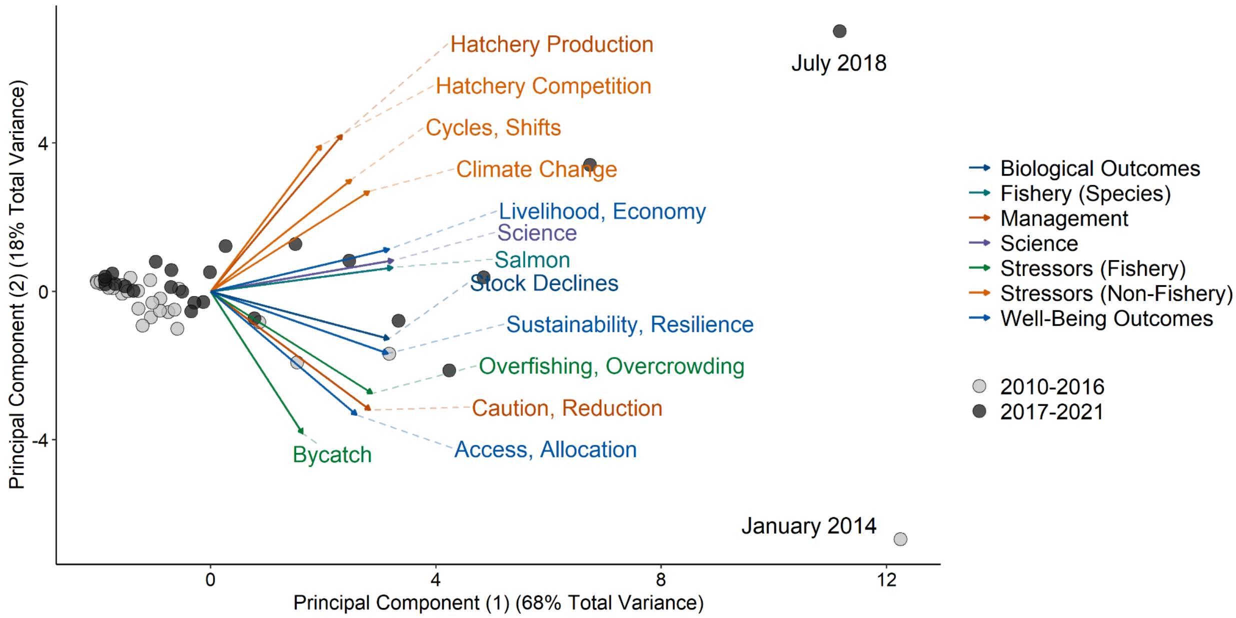


**Figure 5.** Categories and data over principal component space. Loadings appear in relative lengths and directions of arrows, indicating their contributions to variance explained by each principal component and their correlations. Months appear in lighter points for 2010-2016 and darker points for 2017-2021. The separation of points suggest impacts of an extreme heatwave across the Gulf of Alaska from 2014 through 2016. The separation of categories suggests a shift in discourse could explain the variance in terms.

## 4. Discussion

Social-ecological system complexity and climate uncertainties facing participants and resource managers in and of Alaska's marine resources hinder adaptation to climate change. Without recognizing and attributing emergent threats to their livelihoods and moving past near-term allocative battles, participants risk missing opportunities for efficient and equitable solutions (Cinner et al., 2018; Matthew Roscher et al., 2018; Van Putten et al., 2016; Wolf et al., 2013).

Meanwhile, resource managers cannot advance proactive policies without the direction and support of fisheries participants and scientists. However, seizing opportunities for fisheries participants to inform resource management requires understanding the broader context of discourse and barriers to climate attribution.

From 2014 through 2016 and in 2019, marine heatwaves led to tremendous changes in the Gulf of Alaska and drove an increase in climate change discourse before the State fisheries management body. Although climate events are just one driver of shifts in discourse captured in comments, the scale of the marine heatwave suggests a critical role. In the years immediately following the heatwaves, there was an unprecedented series of fishery closures and disasters in the region, leaving many coastal communities grappling with tremendous losses in income due to both direct and indirect impacts (Seung, 2017; Seung et al., 2021). Due to the lags from marine heatwaves' occurrence to their effects on fisheries, some impacts of recent marine heatwaves were contemporaneous with the economic and social impacts of COVID-19 (National Marine Fisheries Service, 2020) – these included the loss of in-person access to fisheries policy with changes in Board of Fish meetings (Haight, 2020).

Despite complex interactions of multiple events affecting fishing livelihoods, the immediacy and scale of marine heatwave impacts brought climate front and center for fisheries participants, evidenced in discourse that focused not only on heatwave effects but also on broader, longer-term ecological changes associated with climate change (Cheung and Frölicher, 2020; Mills et al., 2013). In essence, heatwave impacts on fisheries appear to have bridged the gap between what are often differing temporal and spatial distributions of climate-driven impacts and fishers' observations of their ecosystems (Van Putten et al., 2016). The catalyzing nature of heatwaves in broader climate fisheries discourse should inform fisheries stakeholders, scientists, and managers advancing climate-focused conversations in a space increasingly filled with allocative battles exacerbated by climate-driven impacts on resources.

Climate attribution is complicated by entangled social-ecological systems of multiple and divergent threats, authorities, and values (Bercht, 2021; Chilvers et al., 2014; Wolf et al., 2013). This attribution can be especially problematic for fisheries participants given the strong tie between their occupation and identity, and the existential threat of climate change to well-being (Bercht, 2021, 2017). Cognitive dissonance takes shape when different beliefs about the world clash for an individual, causing internal mental conflict (Festinger, 1962). This manifests in comments to the Board wherein fisheries participants recognize climate impacts on their fisheries systems, but ultimately attribute changing fisheries access and opportunities to long-standing allocative conflicts. Such defaults may reflect the relative ease of attribution to existing mental models over complex and novel schemas for climate-driven change (Van Putten et al., 2016), but also the ultimate need of fisheries participants to maximize their allocations in the face of dwindling resources.

A nuance to research on fishers's attribution of climate-driven changes (Bercht, 2021, 2017; Van Putten et al., 2016) is the use of science in polarizing comments in Alaska over hatchery salmon production and its implications for wild stocks in the face of climate change. Harrison and Gould's (2022) exploration of public perceptions of hatcheries revealed similar polarization and divergent use of science to bolster claims regarding the role of hatcheries in the face of climate change. Furthermore, the authors found those who oppose hatcheries express concerns about hatchery water use and the contribution of hatchery fish towards exacerbating other climate stressors, including dissolved oxygen depletion (ibid). Whereas in previous research scientific complexity over climate phenomena was dismissed by fishers in favor of existing mental schemas for attribution, in comments to the Board and other fisheries discourse in Alaska (Harrison and Gould, 2022), divergent science on interactions of wild and hatchery salmon seems to feed entrenched viewpoints largely defined by those who do and do not directly benefit from hatchery production.

The availability, accessibility, and complexity of science can undermine attribution of marine ecosystem changes to climate change amongst marine resource users and fisheries participants (Barnes et al., 2022; Van Putten et al., 2016). Yet the increasing incorporation of scientific research in relation to climate change within comments to the Board points to a growing role for climate science in participants' cognitive processes. This implies that clear messaging on climate science and fisheries impacts could ease cognitive dissonance, build the learning domain of adaptive capacity (Barnes et al., 2022; Cinner et al., 2015; Cinner and Barnes, 2019), and enable attribution of impacts to climate change. However, that communication is most effective when it is consistent, collaborative, and grounded in local knowledge and value systems, which in turn necessitates time, funding, and a shift in institutional priorities for academics (Kelly et al., 2020).

Public discourse in fisheries management provides opportunities for policymakers and scientists to engage with participants on adaptation pathways. These processes are especially important with the increasing impact of climate change on fisheries systems, accelerating environmental change, and the associated pace of management and public input. The potential for maladaptation is apparent in allocation battles throughout public comments; misattributing climate impacts to allocation could discourage effective adaptation (FAO, 2016). However, participants also describe mechanisms to synchronize those mental processes by building their own resilience pathways, bridging fishing identities with protection, conservation, and restoration efforts (Gianelli et al., 2021). Exploring these linkages for fishers along with improved climate science communication can foster empowered adaptation.

Future expansions of this research could include considerations of commenter characteristics, similar to Krupa et al.'s (2018, 2020) demographic variables as well as attributes evident from the comments themselves (i.e., specifying the types of fisheries one participates in, tenure, family history, etc.). While time-intensive for coding due to the nature of the comments, such an analysis would illuminate the roles of individual or organizational characteristics in informing policy recommendations, use of science, and cognitive pathways in climate discourse. Understanding these differences would clarify where targeted efforts at bridging knowledge systems and finding common ground for policy discourse may be most effective.

## 5. Conclusions

Online public comment submission processes over the last two decades and virtual meeting platforms over the last several years have provided more extensive public input into fisheries management processes in Alaska and elsewhere. The discourse within those comments, while not as deep and rich as that provided through in-depth qualitative methods, provides insight into the breadth of thought by fisheries participants and stakeholders on a given issue. This may be particularly pertinent in the context of climate change impacts on fisheries systems, given the rapid nature of change and how that is accelerating and complicating management and public comment processes. The methods presented herein can be applied in similar contexts to systematically examine big qualitative data with established quantitative methods for data exploration. Coupled with a traditional grounded theory approach to in-depth analysis of the climate comments themselves, this method can expand the research toolbox of breadth-and-depth methods for big qualitative data. Future iterations of this research should examine broader applications of this method to other fisheries management systems to understand whether similar relationships exist between stressors, scientific and management paradigms, and well-being variables within different fishery systems in relation to climate change.

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