From Shorelines to Social Media: Mixed-Methods Insights into Urban Fishing Practices, Policy Gaps and Culture in the Digital Age

Timothy H. Frawley[1*], Maryam J. Krauss[2], Plengrhambhai S. Kruesopon[3], Roya Meykadeh[3], Taylor Triviño[4], Emma Gee[5], Jennifer Selgrath[6], Larry Crowder[2], Rachel Seary[1,7]

[1] Institute of Marine Science, University of California Santa Cruz, Santa Cruz, California, United States of America
[2] Duke University Marine Laboratory, Nicholas School of the Environment and Earth Science, Beaufort, North Carolina, United States of America
[3] Hopkins Marine Station, Stanford Doerr School of Sustainability, Pacific Grove, California, United States of America
[4] School of Aquatic and Fishery Sciences, University of Washington, Seattle, Washington, United States of America
[5] Environmental Studies Department, University of California Santa Cruz, Santa Cruz, California, United States of America
[6] California Marine Sanctuary Foundation, Santa Barbara, California, United States of America
[7] Durrell Institute of Conservation and Ecology, University of Kent, United Kingdom

*Corresponding author; University of California Santa Cruz, tfrawley@ucsc.edu

Recreational and subsistence fishing are globally significant forms of marine resource use, contributing to food security, cultural identity, and social well-being across diverse coastal communities. Yet these non-commercial sectors are often overlooked in formal fisheries monitoring and governance. In California's San Francisco Bay Area, non-commercial fishers represent a wide range of backgrounds and motivations, yet remain underrepresented in marine policy and management. Previous research has struggled to differentiate between different types of sport and subsistence fishing practices, especially among shore- and pier-based fishing communities. This study addresses these gaps by using a novel, mixed-methods approach (leveraging qualitative insight to contextualize and interpret scalable digital data), to analyze how different groups of non-commercial fishers are driven by nuanced motivations while exhibiting unique fishing practices and strategies. Drawing on semi-structured interviews and a database of ~40,000 social media posts (2014-2023), we document differences in behavior, knowledge, and meaning across regional recreational and subsistence fishing subcultures. Our results challenge the assumption that the activities of these non-commercial fishers are marginal or unstructured, revealing strategic species targeting, rich place-based knowledge, and complex adaptive responses to social and ecological change. In demonstrating the value of non-traditional data sources in documenting overlooked patterns of participation and adaptation, we advocate for marine resource management and policy approaches that recognize diverse user groups, foster inclusive participation, and support equitable coastal resource access.

1.0 Introduction

A comprehensive understanding of how different types of resource users interact with the marine environment is critical for effective and equitable fisheries monitoring and governance [1, 2]. However, the traditional data sources (e.g., commercial landings, licensing statistics, and vessel registries) driving much of modern marine resource management and policy often fail to capture the full spectrum of marine resource use [3]. In many regions the nature and extent of non-commercial fishers' (i.e., individuals who fish for personal use, recreation, or cultural purposes, rather than for profit) interactions with the marine environment may be overlooked by formal, top-down monitoring programs. Yet these individuals are increasingly recognized as participating in culturally important fisheries with significant ecological impact [4, 5]. In many regions, non-commercial fishers outnumber those engaged in the commercial sector, and are often well-equipped, highly mobile, and extremely efficient at finding and catching fish [6].

In order to address the activities, needs, and vulnerabilities of user groups underrepresented and underserved in coastal management processes to-date [7], there is growing interest in incorporating quantitative and qualitative insight from alternative data sources [8, 9]. In recent years, social media data has increasingly been recognized as a valuable, low-cost tool for real-time monitoring of coastal resource use [3, 10, 11] and for detecting behavioral response to ecological and regulatory change [12].Yet limited effort has been made to advance scientific understanding of how such digital signals correspond to boots-on-the-ground fishing activity, particularly across urban and/or culturally diverse settings.

The iconic California Coast of North America is an area known for its abundant ocean life, readily accessible marine resources, and diverse coastal communities and user groups. Though efforts have been made to engage coastal stakeholders via the Marine Life Protection Act (MLPA) and other marine spatial planning and resource allocation initiatives, the engagement of commercial and recreational fishing lobbies has often been prioritized over that of other more informal and/or underrepresented groups [7]. Previous studies focused on

California recreational fisheries have frequently failed to discern recreational fishers motivated by sport and pleasure from those motivated by food security and/or other more complex relational and subjective values [see 13, 14]. Those studies which have made an explicit effort to move beyond licensed and vessel-based recreational fishing activity to consider California pier and shore fishers suggest that such groups are more likely to include immigrants, ethnic minorities, and non-English speakers [15, 16]. Despite possessing deep, place-based knowledge of local species and ecosystems and exhibiting a high degree of dependence on marine resources for nutrition and wellbeing, they have been largely overlooked in formal assessments of fisheries effort, impact and access [17].

Here we adopt a mixed methods approach to explore the diversity of fishing practices, values, and adaptations within the non-commercial fisheries across the San Francisco Bay Area (California, USA). Combining qualitative insight obtained from semi-structured interviews (n = 12) with a quantitative analysis of social media databases encompassing 41,464 posts documenting regional fishing activity between 2014-2023, we a) describe variation in fishing participants, strategies, and activities leveraging (and ground-truthing) a new and replicable method for extracting quantifiable data from large volumes of social media activity; b) use content analysis to identify and compare motivating values across different recreational fishing cultures and subgroups; and c) explore the capacity of social media data to characterize longitudinal trends in fishery system and detect real time adaptation and response to emergent ecological and regulatory changes. By combining grounded, qualitative insight with scalable digital data, this study contributes to a more nuanced understanding of how informal or under-recognized user groups engage with marine ecosystems. In doing so, we hope to highlight the importance of inclusive and culturally responsive approaches to marine resource management that acknowledges the diversity of coastal communities and user groups and reflects their heterogeneous needs and priorities.

2.0 Methods

2.1 Semi-Structured Interviews and Qualitative Data Analysis

To better understand non-commercial fisheries in the San Francisco Bay Area and inform the analysis of social media data, we conducted semi-structured interviews (Longhurst 2003) with 12 individuals in the summer of 2023. Interviews explored how different individuals interacted with the ocean, their motivations for doing so, and how their fishing activities (and the benefits they derived from fishing) were impacted by regulatory and/or environmental change. Initial subjects were recruited via Instagram direct messages targeting users of the hashtag

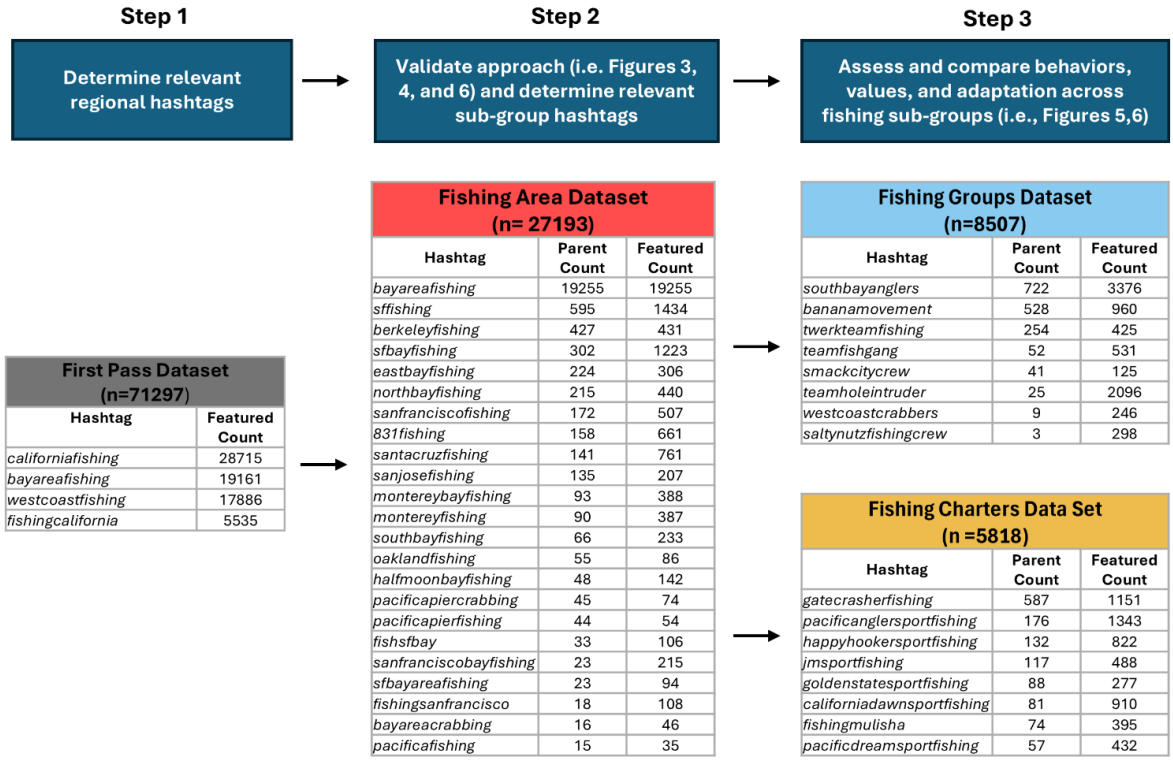

Figure 1. Schematic displaying the sequential, iterative process by which the different datasets (i.e., the Fishing Areas, Fishing Charters, and Fishing Groups datasets) used for analysis were assembled. *n* values refer to the total number of posts in each dataset, *Featured Count* refers to the number of posts containing each hashtag within the indicated dataset, while *Parent Count* refers to the number of posts containing each hashtag within the parent dataset (i.e., the dataset referenced in the previous step).

#bayareafishing; additional participants were identified through snowball sampling [18]. Interviews were conducted over Zoom, transcribed using Grain transcription software, and analyzed in NVivo using inductive coding and a grounded theory approach [19, 20]. All human subjects research was conducted in accordance with research protocols approved by the University of California Santa Cruz (protocol #HS-FY2023-193) and Stanford University (protocol #70729) Institutional Review Boards.

2.2 Social Media Web Scraping and Database Construction

To obtain social media data, we developed an iterative, sequential approach reliant on a custom web scraper produced and maintained by Apify (i.e., apify/instagram-hashtag-scraper; **Figure 1**). This scraper procures data (i.e., images, URLs, comments, likes, user ID, user-provided locations, timestamps, mentions, captions, etc.) from all Instagram posts using one or more specified hashtags. In *Step 1*, we scraped posts using 4 of the most popular hashtags (as inferred by an initial scoping review of relevant posts) broadly related to fishing in California (i.e., #californiafishing, #bayareafishing, #westcoastfishing, #fishingcalifornia), generating a First Pass dataset of 71,297 posts. We sorted all the unique hashtags used in the First Pass dataset by relative frequency and retained a list (n = 23 hashtags) of those that a) explicitly referenced fishing in a specific geographic area between San Francisco Bay and Monterey Bay (i.e., #berkeleyfishing, #santacruzfishing, #pacificapierfishing, etc.); and b) were featured in > 15 unique posts within the First Pass dataset. In *Step 2*, we re-scraped using the 23 regional hashtags

to create the Fishing Areas dataset (n = 27193 posts), which served to validate our approach (*Section 2.3*) and generate targeted hashtag lists for fishing charters (i.e., passenger vessels for hire) and thematically organized fishing groups. For fishing charters, we selected the eight most frequently used hashtags linked to charter fishing businesses; for fishing groups, we selected the eight most frequently used hashtags associated with clubs and organizations associated with shore, kayak, or pier fishing (excluding hashtags where > 25% of posts included photos with motorized vessel imagery). In *Step 3*, we re-scraped using these lists to produce Fishing Charters (n = 8507 posts) and Fishing Groups (n = 5818 posts) datasets that we used to explore diversity in fishing behavior, motivations, and adaptation (*Sections 2.4 & 2.5*).

2.3 Digital Fisheries Data Processing & Validation

To evaluate whether Instagram captions could serve as a proxy for fisher behavior and species targeting, we manually reviewed a random subset of 1,400 posts (~5% per component hashtag) from the Fishing Areas dataset. Marine species depicted within the photographs associated with each post were manually identified (i.e., 'observed') and tabulated using a species identification key constructed from information provided by the California Department of Wildlife marine species portal (see: https://marinespecies.wildlife.ca.gov/). In order to reduce the number of categories used for analysis, we collapsed individual species into 10 broader taxonomic groupings (i.e., the Crab grouping consisted of both Dungeness Crab (*Metacarcinus magister*) and Rock Crab (*Cancer productus)*; the Shark grouping consisted of Leopard Shark (*Triakis semifasciata*), Brown Smoothhound Shark (*Mustelus henlei*), and Broadnose Sevengill Shark (*Notorynchus cepedianus*), etc.) and an Other category (which consisted of White Seabass (*Atractoscion nobilis*), Cabezon (*Scorpaenichthys marmoratus*), Jacksmelt (*Atherinopsis californiensis*), and Tuna species (*Thunnus spp.*)). Freshwater species and individual species identified less than 3 times in the random subset of 1,400 posts were excluded from the analysis. In instances where multiple taxonomic groupings were shown, we counted each separately; however, when multiple individuals within the same taxonomic grouping were shown, the grouping was only counted once.

As part of this review, the species identification key was iterated to include a running list of nicknames commonly used to reference species and/or their corresponding taxonomic group (i.e., California halibut (*Paralichthys californicus*), were commonly referred to as 'halibut', 'halis', 'butt', 'flatty' and/or 'flatties'). To compare the number of times each species was mentioned in the captions and/or hashtags of posts included in our random subset with the number of times that the corresponding taxonomic groupings were manually identified, we used the R programming [21] function 'grep' to identify posts with captions and/or hashtags containing text strings (i.e., names and nicknames) associated with that species grouping. For example, to identify posts referencing California halibut, we searched for posts containing the strings *halibut, halis, butt, flatty* or *flatties*. Linear regression was then applied to the 1400 post-subsample to assess the degree to which the number of times a species was observed could predict the number of times that it was mentioned.

2.4 Characterizing Non-commercial Fishing Strategies and Activities

To determine the harvest portfolio diversity and center of gravity of the individual hashtags associated with distinct fishing groups and charter fishing operations, we prepared data subsets in which only posts using that specific hashtag were retained. Harvest portfolio diversity was assessed using the inverse Simpson's index, in which higher values are indicative of greater

diversity [22, 23], as applied to relative percentages (i.e., the number of posts mentioning species contained within each taxonomic group divided by the total number of posts mentioning any species contained within any taxonomic grouping). To calculate the geographic center of gravity of fishing activity described by each fishing group and charter, we first sorted the location tags used in the Fishing Areas dataset by relative frequency and assigned latitude and longitude coordinates (obtained using Google Maps) to any location tag that was used more than 5 times. This list of georeferenced locations was limited to only those points with < 121° W Longitude and between 36.5° N and 39° N Latitude (n =2 11) to constrain the analysis to those locations within the study area (coastal or near-coastal counties in central California comprising the broader San Francisco Bay Area). We then merged this database with the subset of posts containing location information for each individual hashtag and calculated the unweighted center of gravity using a formula derived from the literature [24].

2.5. Assessing Diversity in Culture, Behavior, and Motivation

To identify and compare the motivations and strategies associated with different fishing groups and fishing charters, we conducted the text mining analysis designed and constructed a series of word clouds using the R package 'wordcloud' [25]. We began by filtering the captions associated with all posts associated with each dataset to only retain words included in a) a list of 2,000+ words associated with positive opinions and/or b) words associated with marine life, nature, and/or fishing activity. The first word list was previously produced by researchers focused on text mining, pattern recognition, and public opinion [26] and has been widely used in sentiment analysis. The second word list was developed by the project team by quantifying the relative frequency of all words used in all captions and retaining those words that were used > 50 times and resonated with one of the three themes of interest (i.e., marine life, nature, and/or fishing activity). Upon obtaining these data subsets, we used comparison clouds to compare the relative frequency of words used within and between our datasets (i.e., comparing the aggregate frequency of words across the Fishing Charters, and Fishing Groups datasets and comparing the frequency of words used by different Groups or Charters within those datasets). The size of each word in each comparison cloud is mapped according to its maximum deviation, with larger words having the most distinct and uneven associations.

2.6 Longitudinal Changes in the Fishery System

To investigate longitudinal changes (2014-2023) in the structure and dynamics of the fishery system, we examined changes in species mentions and posting activity over time. We looked at annual differences in the number of posts, the number of accounts posting using hashtags of interest (i.e., 'posters'), and the changes in the relative frequency that individual species were mentioned (i.e., the number of times a given species/taxonomic group was mentioned in a year divided by number of times all species/taxonomic groups were mentioned in that year). Our analysis of changes in the relative frequency of species mentions over time used a combined data set (n=23,471 following the removal of duplicate posts present in multiple datasets and posts that didn't mention any of our focal species) while changes in the number of posts and posters was assessed individually for the Fishing Areas, Fishing Charters, and Fishing Groups datasets.

To assess the capacity of social media to quantify the impacts of and response to emergent shocks and stressors in near real-time, we used California's 2023 salmon fishery closure as a case study. In 2023 commercial and recreational salmon fisheries across the state

were closed to protect declining salmon populations associated with drought, habitat degradation, poor water management policy, and increasing climate variability [27]. To test the hypothesis that this closure had an impact on fishing strategies and species targeting, we assessed whether individual species were mentioned more or less frequently during 2023 as compared to other years across the Fishing Charters and Fishing Groups datasets.

3.0 Results

Our quantitative analysis of extensive social media datasets (contextualized and interpreted using semi-structured interviews) reveals substantial variation in fishing practices, motivations, and adaptive response characteristics of the San Francisco Bay Area's diverse non-commercial fisheries. Below we a) validate our approach and compare annual and seasonal trends in species targeting inferred by social data to those described by fishers in semi-structured interviews; b) compare the fishing strategies, harvest portfolios, and motivating values of two, distinct non-commercial fishing subcultures (i.e., Fishing Groups vs. Fishing Charters); and c) investigate longitudinal changes (2014-2023) in the structure and dynamics of the fishery system. In addressing this final objective, we assess the capacity of social media data to quantify the impacts of and response to emergent shocks and stressors in near real-time.

3.1 Variation in Fishing Participants, Strategies and Activities

Fishing strategies and activities inferred via a quantitative analysis of social media (i.e., Instagram) posts made by Bay Area non-commercial fishers broadly corresponded with those articulated in semi-structured interviews. The most common species mentioned (i.e., species

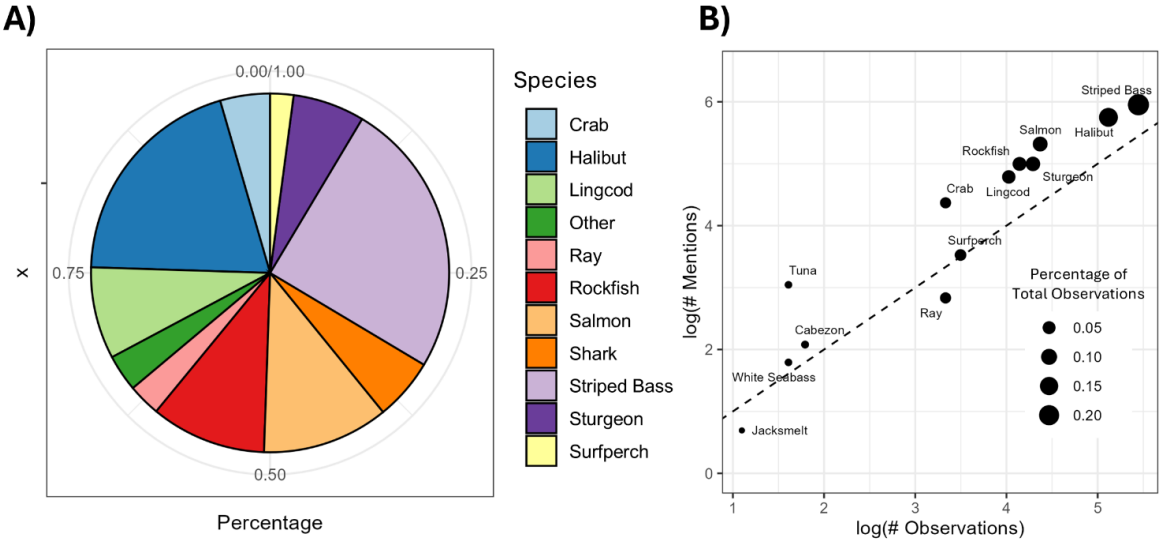

Figure 2. Comparison of species that were observed (i.e., manually identified from photos) and species that were mentioned (in post captions) in the Fishing Areas dataset. **A**) Shows the relative frequency at which marine organisms embedded in different species categories were observed across the complete data set (n=27,887 total mentions, with posts frequently mentioning more than one species) , while **B)** shows the broad and significant (R^2 = 0.894, $p < 0.0001$) correspondence between the log-transformed number of times different species were observed and the log-transformed number of times they were mentioned in post captions and/or hashtags in a 1,400 row random subset (~5% of each component hashtag). In **A)** tuna, cabezon, white seabass, and jacksmelt are lumped together in the "Other" category while in **B)** these species are displayed individually.

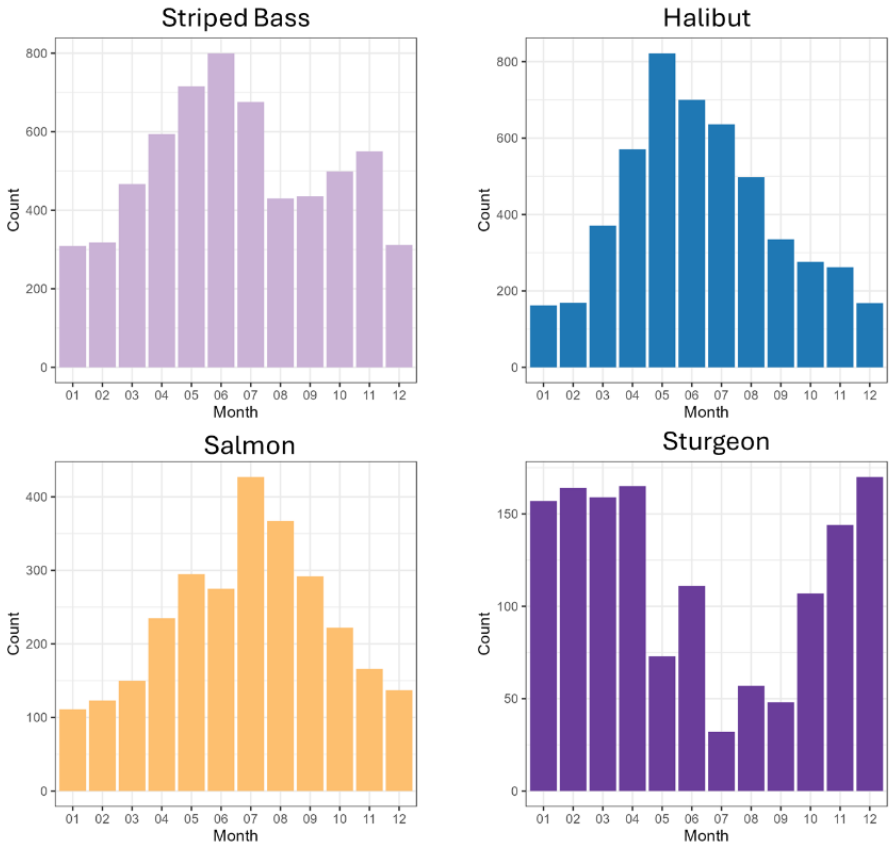

Figure 3. Seasonal distribution of mentions across the complete extent (2014-2023) of the Fishing Areas dataset for the four commonly observed species groupings (i.e., Striped Bass, Halibut, Salmon, and Sturgeon).

named in the text captions and/or hashtags which accompany photos within social media posts) within our Fishing Areas data set were Striped Bass (24.9 %), California Halibut (19.9 %), Salmon (11.4%), and Rockfish (10.4 %) (**Figure 2A**). Overall, 15783 of the 27193 of the posts (58.3%) in this dataset mentioned one or more of our focal species. A comparison of species observed (via manual identification) with species mentioned in a random subset of 1,400 posts (**Figure 2B**) confirmed that species mentions can be used as an accurate proxy for photographically documented catch ($R^2 = 0.894$, $p < 0.0001$).

Examination of the monthly distribution of records across some of the most commonly mentioned species reveals distinct seasonal patterns driven by individual prioritization, species biology and life history, and local fishing regulations and restrictions (**Figure 3**). Salmon and halibut landings peaked during early-summer months (in July and May, respectively) when the species were reported to move into warmer, shallower waters. While fishers reported being legally permitted to target halibut year-round, irrespective of local abundance, the salmon fishery has a distinct start date which functions to concentrate effort later in the summer season. Striped Bass mentions exhibited a bimodal peak (June and November), with rivers and estuaries supporting productive fishing during spring spawning migrations and summer and fall landings in ocean waters peaking in summer and fall when more active feeding activity is observed [28]. These biological patterns are likely reinforced by preferences that influence how anglers choose to prioritize their effort; as one interview respondent described, *"In the summers, I hit the bay. So we're looking at the halibut, striper, and salmon... Now if you're asking what's my favorite, it's salmon number one,"* (Pier and Shore Fisher, Interview #8). In contrast, Sturgeon fishing

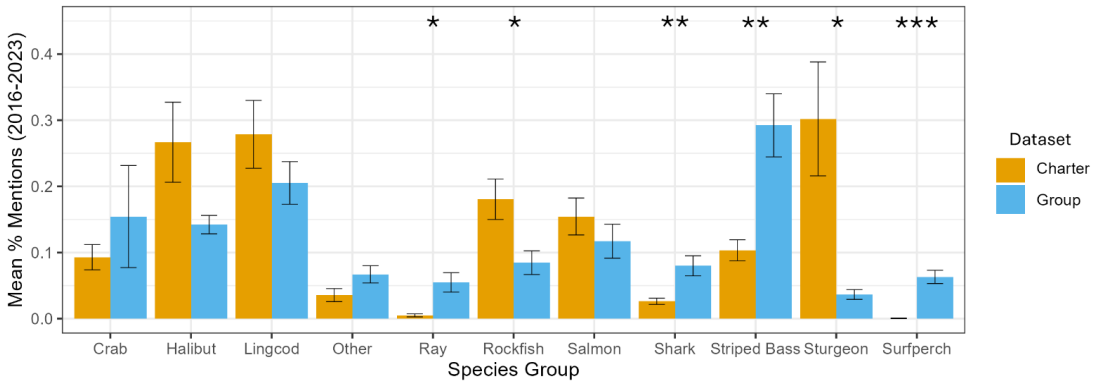

Figure 4. Comparison of the annual relative frequency of species mentions (+/- S.E.) between the Fishing Groups and Fishing Charters datasets (2016-2023). Significant differences (as inferred by the results of a Student's T-test) are denoted by an asterisk (* $p < 0.05$, ** $p < 0.01$, and *** $p < 0.001$).

mentions peaked during the winter and early spring months, when activity associated with other species is minimal, as sturgeon migrate from ocean environments into freshwater systems for spawning [29].

3.2 Variation in Fishing Strategies and Behaviors across Non-commercial Fisheries

Our interviews revealed distinct subcultures within the recreational fishing community shaped by fishing methods, geographic access, and socioeconomic background. Shore-based and/or pier fishers commonly found in urban areas often included individuals from immigrant or working-class backgrounds that emphasized the importance of place-based knowledge and local communities of practice. One respondent recalled being taught specific techniques by older pier fishers, "*They taught me a few things, like how to throw cast nets and catch bait around the piers…the passion just kind of grew…*" (Pier and Shore Fisher, Interview #9). Halibut, Striped Bass, Surfperch, and Dungeness and Rock Crab were reported as the most prized and reliable catches by pier and shore fishers, while Leopard Sharks and Bat Rays were sometimes additionally and/or opportunistically targeted in shallow, urban waters. While pier and/or shore fishing was considered an economically inclusive and accessible activity, boat fishing required substantial investment in fishing gear and necessitated the ability to navigate comparatively complex restrictions and regulations. Boat fishers, reliant on personal watercraft or vessels for hire (i.e., charter fishing vessels) to target species less accessible from shore (i.e., Salmon, Tuna, Lingcod, and Rockfish), claimed to have a broad environmental perspective and more advanced technical knowledge of relevant equipment, seasonal cycles, and species-specific techniques (Boat Fisher, Interview #2; Boat Fisher, Interview #6).

Analysis of more granular datasets (i.e., the Fishing Groups and Fishing Charters datasets, see **Figure 1**) used to isolate and compare shore-based non-commercial fishers to those associated with charter fishing boats confirmed the existence of distinct harvest portfolios and fishing strategies. A comparison of the average proportion of species mentions (i.e., the number of times a species group was mentioned in a year divided by the total number of mentions across all species groups) between the Fishing Groups and Fishing Charters datasets (**Figure 4**), revealed significant differences in species targeting. Student's t-tests indicated that Rockfish ($p < 0.05$) and Sturgeon ($p < 0.05$) were mentioned significantly more frequently by charter fishers. In contrast, Striped Bass ($p < 0.01$), Sharks ($p < 0.01$) and Surfperch ($p < 0.001$) were mentioned

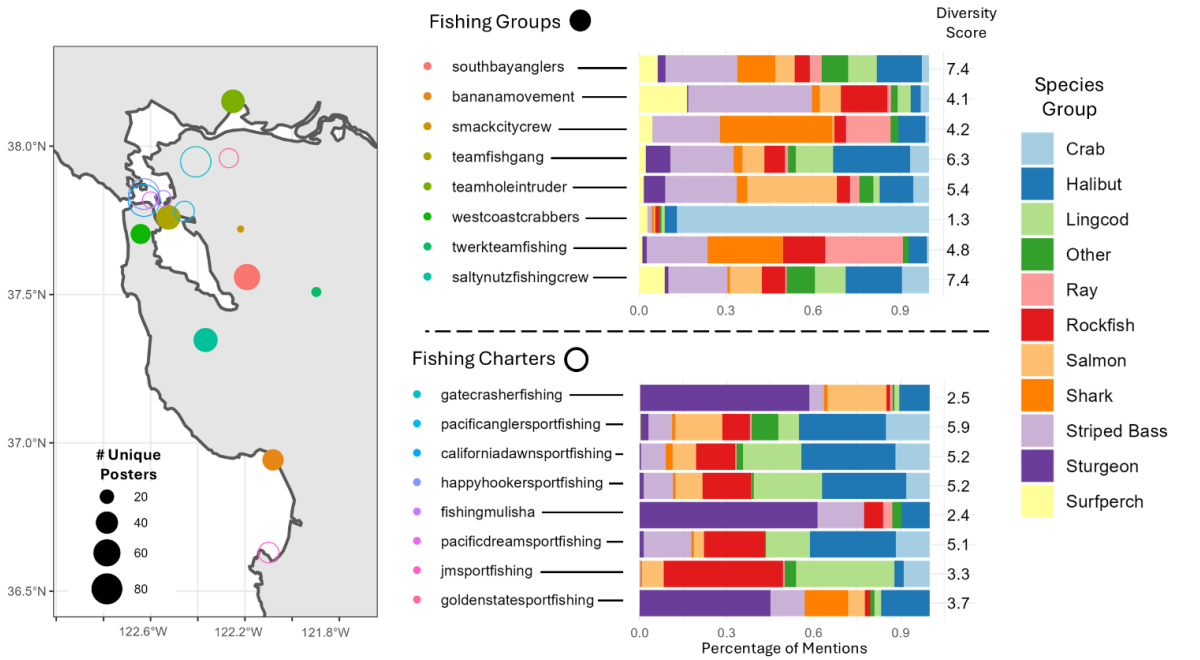

Figure 5. Spatial distribution and harvest portfolios of individual hashtags represented in the Fishing Groups and Fishing Charters datasets. The left panel portrays the center of gravity for different fishing groups (filled points) and fishing charters (open points) as assessed from associated posts that included a georeferenced location tag; points are sized according to the total number of unique posters using the hashtag across all posts within each dataset. The right panels illustrate the harvest portfolios of each fishing group and charter, as assessed by the relative proportion of species mentions, alongside a corresponding diversity score (calculated using the inverse Simpson's index).

significantly more frequently by members of fishing groups focused on shore and/or pier fishing (**Figure 4**). Comparison of center of gravities inferred by the georeferenced location data associated with the posts of each dataset suggests that fishing charter activities were concentrated around the ports and marinas of San Francisco Bay (w/ the exception of *jmsportfishing*, based in Monterey). Fishing groups, in contrast, had a somewhat broader extent as distributed across the Peninsula and the East Bay (**Figure 5**). Overall, inverse Simpson's diversity index values (**Figure 5**) revealed that the average harvest portfolio diversity estimated for individual fishing groups (mean = 5.11 +/- S.E. 0.71) was modestly, though non-significantly (p = 0.29) more diverse than the average harvest portfolio estimated for fishing charters (4.16 +/- S.E. 0.47). Indeed, a number of shore and pier fishers referred to their fishing strategies as flexible and opportunistic, prizing resourcefulness and creative problem-solving (Pier and Shore Fisher, Interview #3; Pier and Shore Fisher, Interview #9). However, substantial variance existed between fishing groups, ranging from those exhibiting broad, generalist fishing strategies (i.e., *saltynutzfishingcrew*, *southbayanglers*) to highly specialized groups organized around a single species (i.e., *westcoastcrabbers*).

3.3 Diverse Cultures and Motivations

Semi-structured interviews conducted with recreational and/or subsistence fishers across the San Francisco Bay Area reflect activities deeply rooted in the social and cultural fabric of the regional, coastal social-ecological system. Individuals reported diverse and interconnected reasons for fishing, ranging from practical needs to personal and subjective motivations. Beyond valuing fresh, self-caught seafood as a healthier (and more affordable) alternative to store-bought

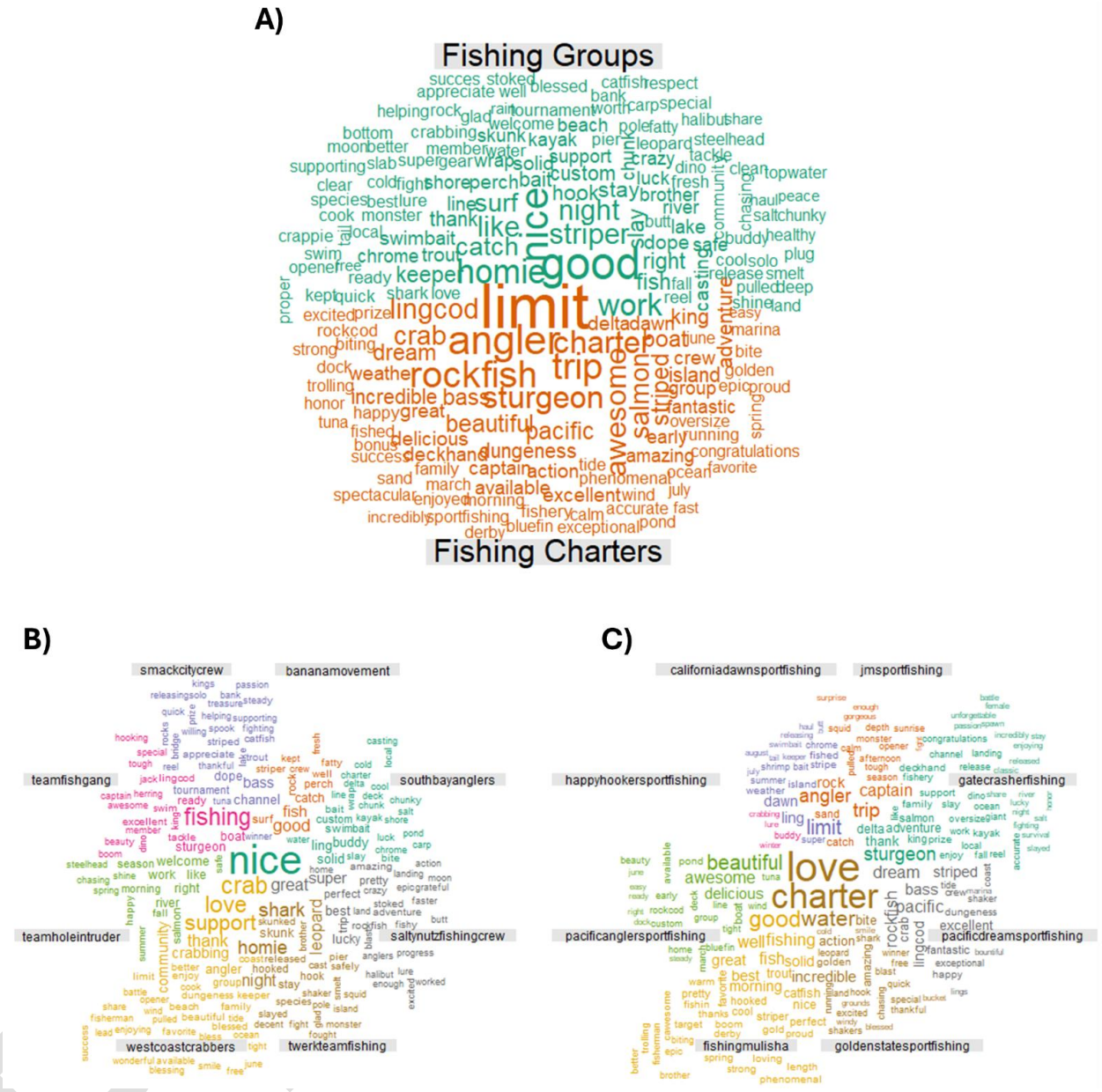

Figure 6. Word clouds used to compare the relative frequencies of different words by hashtag between the Fishing Charters, Fishing Groups, and Fishing Areas datasets (**A**). In constructing each comparison cloud, we only retained words from the post captions that were included a list of 2,000 words associated with positive opinions and/or feelings commonly used in sentiment analysis [26] and/or list of words (assembled for the purpose of this project) that were used > 50x across all captions in the Fishing Areas dataset and were associated with marine life, nature, and/or fishing. Disaggregated analysis used to compare the relative frequency of words within different data sets are shown in panels **B)** Fishing Groups, and **C)** Fishing Charters.

fish (Boat Fisher, Interview #6; Pier and Shore Fisher, Interview #8) fishing was often described as an activity that helped strengthen social bonds (Boat Fisher, Interview #3; Pier and Shore Fisher, Interview #4; Boat Fisher, Interview #6). Fishing provided an opportunity to spend meaningful time with friends and family, passing down knowledge concerning specific practices from one generation to the next, and was frequently associated with a sense of belonging .

Indeed, important aspects of regional, cultural identity were sustained by the rituals and traditions through which specific species are caught, shared, and/or consumed communally (i.e., serving fresh Dungeness crab for Thanksgiving). Beyond that, fishing was described as a source of peace and tranquility while offering a unique opportunity to disconnect from the modern, technology-focused world and practice self-reliance. As one respondent described, "*I wish I could explain it…it's just kind of like your happy place. You get out there, you're away from everything. Just kind of like a peaceful thing...*" (Boat Fisher, Interview #6).

Wordclouds used to parse the captions associated with posts within and across all three social media datasets helped characterize nuances in the sub-cultures associated with different types of non-commercial fishing activity (**Figure 6**). As compared to the Fishing Groups data sets, Fishing Charters posts more frequently emphasized "excitement", "adventure", and "action", while using superlative language such as "amazing", "fantastic", "awesome" or "exceptional". In addition, a major focus and goal of Fishing Charters appeared to be competition and/or catch maximization, as inferred by frequent use of "limit" in addition to "success" and "congratulations". In contrast, Fishing Groups more frequently used informal slang words (i.e., "dope", "stoked" "slayed", "fatty"), emphasizing fishing as an escape from "work" that offered the opportunity to connect with "homie[s]" and "brother[s]". Expressions of gratitude and connection were more frequent (see "love", "respect", "appreciate", "thank", and "blessed") and, rather than maximizing catch, a primary goal of shore and pier based fishers appeared to be avoiding the "skunk" (i.e., going home with zero catch). A final observation worth noting concerns the gendered aspects of much of the posting language, particularly evident for Fishing Groups. Though a female interview respondent discussed gender-based perceptions of competence or authority within male-dominated fishing culture (Pier and Shore Fisher, Interview #4), she and others expressed optimism moving forward, citing increasing female participation attributed to fishing organizations dedicated to community and inclusion (Pier and Shore Fisher, Interview #4; see *westcoastcrabbers* **Figure 6B**) and shifting cultural norms (Pier and Shore Fisher, Interview #8).

3.4 Changes Over Time

Across the interviews, fishers noted shifts in the environment, regulatory landscape, and fishery participation that had influenced their activities during recent years. There was widespread agreement on the growing unpredictability of seasonal runs and species availability. While some respondents described warming waters and ecosystem shifts responsible for changes in migration patterns and population dynamics of salmon and tuna species (Boat Fisher, Interview #2; Boat Fisher Interview #6), others focused on how recent storm events had physically altered nearshore habitat that once supported productive crab and halibut fishing (Kayak & Boat Fisher, Interview #1; Pier and Shore Fisher, Interview #4). Policy approaches and interventions designed to address such changes were largely perceived as short-sighted, ineffective, and inequitable, with the 2023 California Salmon fishery closure repeatedly referenced as a salient and timely example of reactive management. With salmon fishing closed, fishing pressure was redirected to halibut across recreational and commercial fishing sectors, resulting in an in-season reduction in the halibut bag limit for recreational fishers. As one respondent described near the end of the season, "*It wasn't until… like, a month ago or something that they changed [the halibut limit] to two. It seems like that was kind of… too late, almost… It would have been nice if that had been changed earlier. In my case, it was fairly obvious that the halibut population was going to be hurt because of the additional pressure*,"

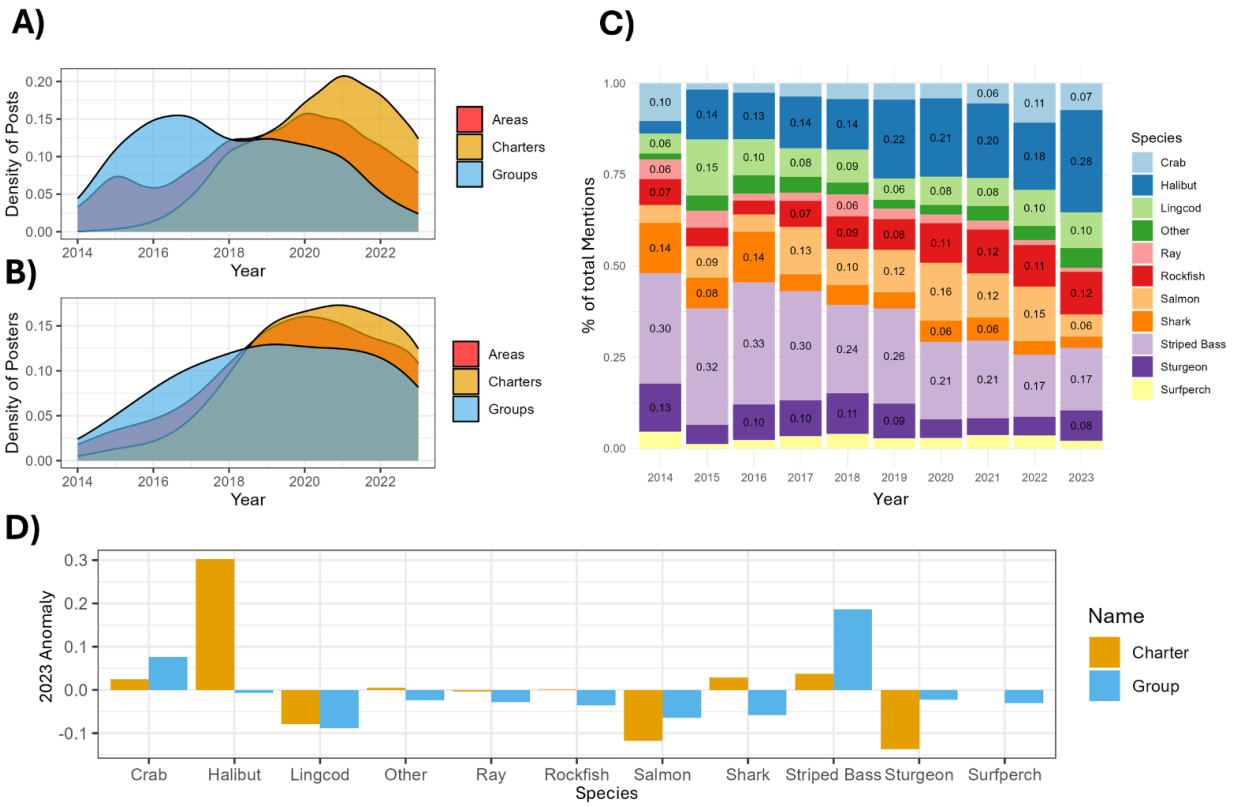

Figure 7. Changes in the nature of posting activity and number of species mentions over time (2014-2023). **A)** and **B)** are density plots illustrating annual changes in the number of posts (**A**) and the number of unique posters (**B**) in each of our 3 datasets (i.e., Fishing Areas, Fishing Charters, and Fishing Groups); **C**) illustrates changes in the relative number of mentions in social media posts by species (i.e., percentage of total mentions) in a single, aggregated dataset and **D**) highlights changes of the relative frequency of species mentioned in the Fishing Charters and Fishing Groups datasets in 2023 as compared to the annual average. Anomaly values > 0 indicate that the species was mentioned more frequently in 2023 as compared to other years and anomaly values < 0 indicate that the species was mentioned less frequently in 2023 as compared to other years.

(Kayak & Boat Fisher, Interview #1). Many interview subjects noted that recent changes in fishing participation had likely functioned to intensify such resource allocation conflicts. With fishing gaining popularity during the COVID-19 pandemic (beginning in 2020) as a socially distanced outdoor activity, many piers and other traditional shore fishing spots were now perceived as overcrowded (Kayak Fisher, Interview #11; Pier and Shore Fisher, Interview #9).

Though complicated by differences in the number and type of posts made each year, time series analysis of social media data (**Figure 7**) confirms many of the large-scale trends and changes to regional, non-commercial fisheries discussed in the semi-structured interviews. Density plots used to examine changes in the number of posts (**Figure 7A**) and posters (**Figure 7B**) over time, reveal a peak in activity roughly between 2020 and 2021 (coincident with the COVID 19 pandemic), though it is worth noting that activity (particularly the number of posts) within the Fishing Groups dataset peaked substantially earlier than it did for either the Fishing Charters or Fishing Areas datasets. Our analysis of changes in the relative frequency of species mentions over time across all 3 datasets (see *Methods*) revealed a declining number of striped bass and shark focused posts as the study period progressed and an increasing number of crab, halibut and rockfish focused posts (**Figure 7C**). A shift in species targeting was particularly evident in 2023. Though the annual number of Salmon focused posts was variable, a substantial

decline in the relative frequency of posts was observed during 2023 when the fishery was closed (though the number did not approach zero as it was difficult to isolate and exclude posts referencing historical activity, future activity, and/or freshwater salmon fishing activity). When comparing species that were mentioned more or less frequently in 2023 in the Fishing Groups and Fishing Charters dataset as compared to other years (**Figure 7D**) overall negative Salmon, Lingcod, and Sturgeon (Charters only) anomalies were most pronounced, while the largest magnitude anomalies were positive as associated with Halibut (Charters) and Striped Bass (Groups).

4.0 Discussion

4.1 Reflections on the Strengths and Weaknesses of Digital Fisheries Data

In data-limited contexts, social media and other digital platforms represent a valuable new opportunity for leveraging user-generated content to enhance fisheries monitoring and governance [5, 10]. Our study demonstrates that social media platforms such as Instagram are capable of providing a rich, near-real-time window into the nature and extent of fishing activity across diverse user groups. Previous research has shown that participatory digital platforms can promote environmental stewardship and build trust between resource users and management agencies by democratizing knowledge production [5, 30]. However, caution is warranted as these emerging tools raise new ethical and privacy concerns, and are subject to inherent biases [30]. Social media data may overrepresent successful catches, visually appealing species, and/or individuals with the interest and technological capacity to document their activities online [30].

A key limitation of our dataset is the underrepresentation of older, non-English-speaking, and subsistence-oriented fishers, who may be active but largely absent from online discourse. Indeed, previous research has documented the importance of subsistence fishing and informal information sharing among Bay Area Tagalog, Vietnamese, Mandarin, and Cantonese-speaking communities [31]. While our semi-structured interviews yielded rich and nuanced insight, our recruitment strategy (i.e., Instagram direct messaging and snowball sampling) necessarily limited the diversity of participants. Future research may explore the utility of more niche social platforms used by diaspora communities (e.g., WeChat). Finally, although we demonstrate a proof-of-concept for scalable behavioral analysis using third-party web scraping tools, challenges persist regarding species misidentification and inconsistent geotagging inherent to user-generated data. Future collaborations with platform-owning enterprises (i.e., Meta Platforms Inc.) could improve the quantity and scope of digital fisheries data (i.e., advanced querying and indexing capabilities, streamlined API access, first-party metadata, etc.) available for research and management and provide additional opportunities for validation. Indeed, as governments increasingly seek to regulate social media platforms to minimize societal harm, ensuring the availability of this type of information (as accessed and analyzed in service of the public good) might be considered a valuable prerequisite of a social license to operate.

4.2 Unlocking the Potential of an Understudied Fisheries Social-ecological System

Despite the San Francisco Bay's extensive coastline and rich maritime heritage [32], relatively little information exists concerning the modern nature and extent of non-commercial fishing undertaken by its ~ 7.5 million residents. Those episodic studies that do exist are narrowly focused on charter fishing activity (as revealed by analysis of interviews, logbooks, and/or observer data; see [33, 34]) or are primarily concerned with the environmental toxicity of

catch [35, 36, 37]. Yet our analysis reveals a layered social-ecological system in which a rich tapestry of resource users engage in diverse activities in pursuit of numerous consumptive and non-consumptive benefits. Indeed, given the historical, ecological significance of the San Francisco Bay estuary (once characterized by large salmon runs and productive fisheries for sardines, herring, sturgeon, striped bass, oysters, and shrimp) and recent improvements in ocean water quality and coastal habitat [38], we would suggest that this is a critical management oversight. As state and federal resource managers have invested substantial resources in fisheries monitoring and enhancement in other parts of the state, the potential of the San Francisco Bay to advance conservation and/or restoration goals remains largely untapped. Likewise, the potential of non-commercial pier and shore-based fishers' fine-scale sampling and ecological knowledge to inform fisheries management remains underutilized [15, 16]. While efforts associated with the CDFW California Recreational Fisheries Survey (CRFS) (established in 2004 but funded sporadically thereafter) have increased the scope and frequency of recreational fishing data collection, catch and effort associated with beaches, banks, and other manmade structures (i.e., fishing piers) have yet to be aggregated and analyzed systematically. In addition to the efforts required to standardize and streamline the collection (and access protocols) for these and other non-commercial fisheries data, we would suggest regional resource managers consider how regular review and consideration of user-generated, digital fisheries data could enhance population and ecosystem level- assessments, build trust with resource users, and identify issues of local concern [23, 39].

4.3 Implications for Inclusive and Adaptive Coastal Governance

In addition to stewarding ecological resources, fishery managers are increasingly tasked with managing for social equity by ensuring the fair distribution of opportunities, benefits, and burdens across individuals and groups of people [40, 41]. Though management approaches designed to maximize the sustainable yield and economic productivity of fish stocks are comparatively well-developed (i.e., catch limits, spatio-temporal closures, etc.), our findings emphasize the need to develop a complementary toolbox to recognize and protect the non-material benefits derived from fishing (i.e., intergenerational knowledge transfer, community bonding, cultural identity, etc.). These benefits, though difficult to monitor and quantify through traditional data sources and approaches, are fundamental to the social fabric of urban coastal communities [2, 17]. Indeed, the continued reliance on narrow data inputs and formal stakeholder engagement process may serve to further marginalize underrepresented groups, including immigrants, low-income residents, and/or multilingual communities for whom participation in non-commercial fisheries is an essential part of individual and community wellbeing [15, 16]. Our mixed methods approach, combining interviews and social media data, helps address this gap by helping to illuminate how fine-scale ecological data is embedded in cultural and demographic patterns of resource use and access. In doing so it may represent a valuable tool for advancing procedural and recognitional justice, increasing the scope of who is counted and considered and what practices are seen as legitimate in formal fisheries management [42]. Procedure and recognition, while important goals unto themselves, are also the first steps in more just distributional outcomes.

5.0 Conclusion

Our analysis demonstrates the value of non-traditional data sources in documenting patterns of participation and adaptation that may be overlooked by traditional marine monitoring

and data collection protocols relied upon resource managers. Formal recognition and consideration of more diverse stakeholders and user groups could help foster broader participation and engagement with ocean and coastal spaces while supporting more equitable resource access. While approaches leveraging user-generated digital fisheries data are likely most effective when embedded in broader commitments to environmental justice and data equity (i.e., targeted outreach designed to minimize biases associated with digital visibility), they may be uniquely positioned to capture dynamic and geographically dispersed social-ecological interactions that are currently overlooked. Given the significant and widespread oceanographic and ecological changes expected to impact California fisheries in the coming decades [43], the need for such tools may become increasingly acute. Recognizing and monitoring shifts in species targeting and fishing behavior in near-real time may facilitate new opportunities for adaptive governance while allowing managers to better anticipate and account for the distributional impacts of management intervention. Indeed, in order to advance equitable fisheries management, we suggest that managers must move beyond assessing fish and habitat to consider the people, practices, and places that give fishing its meaning and consider how they are impacted by social and ecological change.

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