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The Influence of Fishers' Behavior on Recreational Fishing Dynamics and Catch: Insights from a Mediterranean Coastal Lagoon

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Abstract: Recreational fishing is practiced by thousands of people in European coastal waters and is steadily gaining popularity. Serving multiple purposes, recreational fishing provides fresh fish for meals, offers leisure, and contributes to traditional ecological knowledge, especially at the local level. Therefore, analyzing its dynamics and catch is a complex task, since they not only depend on the environmental features but also on the behavior of fishers. In coastal areas, however, most recreational fishers remain unmonitored, making it difficult to obtain data on their impact on fish stocks. This is particularly evident in the Venice lagoon, where we conducted a comprehensive study aiming to characterize recreational fishing dynamics. We collected data through interviews, online questionnaires, and remote sensing techniques, including satellite imagery photointerpretation and machine learning algorithms. Our findings reveal spatial and temporal variations in fishing activity, with certain areas and times experiencing higher fishing pressure. This highlights a seasonality in fishing activity and a pattern in fishers' behaviors that are associated with fish migratory dynamics. Such an association demonstrates the local fishers' understanding of the fish lifecycle phases and the environmental conditions of the lagoon. Regarding the catch, the most targeted species are seabream (*Sparus aurata*), seabass (*Dicentrarchus labrax*), and cuttlefish (*Sepia officinalis*), with estimated total catches of 18.65 t per year, 15.82 t per year, and 8.36 t per year, respectively. However, our results showed a significant disproportion between the biomass caught by two different groups of fishers that differ in terms of fishing trip frequency, success rate, and catch. While the average catch of the first group, representing most recreational fishers, might be considered of low impact, the catch of the second group, encompassing recreational fishers who fish with very high frequency and efficiency, is substantial in the context of the lagoon ecosystem. Indeed, even considering a conservative estimate, recreational fishing in the Venice lagoon accounted for approximately 2% of the catch of cuttlefish and 17% of the catch of seabream compared to commercial fishing catch, whereas the catch of seabass by recreational fishing approached that of commercial fishing. Therefore, the implementation of a periodic monitoring program utilizing methods such as machine learning algorithms and remote sensing technologies could support the management of recreational fishing dynamics. We also suggest that participatory processes involving both professional and recreational fishers may aid in defining shared approaches and bottom–up initiatives, ensuring enjoyment as well as sustainable uses of coastal areas.

Keywords: fishing management; Venice lagoon; recreational fishing impact; catch; ecosystem services; remote sensing

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1. Introduction

Recreational fishing is an activity people carry out especially in their spare time and is the pursuit of catching fish for leisure, competition and own consumption rather than for commercial purposes. As a widespread activity that in general is socially accepted, recreational fishing is appreciated by numerous enthusiasts worldwide and practiced in almost all aquatic environments [1]. Recreational fishers typically engage in this activity with the primary goal of experiencing the thrill of the catch, while enjoying the natural environment by spending time outdoors [2,3]. For many people, to engage in recreational fishing is also a way to escape the routine of daily life and relieve stress [4,5] through the enjoyment of nature, as well as leveraging on more subtle psychological mechanisms such as the excitement and satisfaction related to agonistic challenges [6], even extending to display of pride [5,7]. Recreational fishing also serves multiple purposes beyond leisure and relaxation, often representing a tradition that fosters social and affective bonds within families and among friends who share the same passions [8].

Due to its multifaceted nature, recreational fishing could be considered an ecosystem service that falls in the middle between the categories of provisioning and cultural ecosystem services; it involves a wide range of uses and forms of appreciation that go from supplying fresh fish for meals when fishing for food and subsistence [9] to providing intangible psychological benefits [4], the latter relying more on the fishing experience rather than on the catch itself. The complexity of these driving factors makes analyzing recreational fishing a challenging task, as patterns of fishing activity depend not only on environmental conditions but also significantly on the behaviors of fishers [6,10]. Understanding fishers' behaviors and their decision in spatial and temporal contexts is therefore essential for interpreting the patterns of recreational fishing activity [11,12]. However, human decision-making processes and the resulting behavior can involve irrational drivers or cognitive pathways that are not easy to predict or monitor. Influenced by both environmental factors and psychological and social motivations, the complex nature and uncertainty of behavioral outcomes add further layers of complexity to the analysis of fishing activities [13]. Consequently, assessing the catch from recreational fishing becomes challenging due to the wide array of variables influencing this activity. These factors range from human decision-making variability to environmental conditions affecting fish distribution, weather patterns, and fishing efficiency [12].

Currently, in Europe, there are no standardized monitoring protocols to accurately quantify catches from recreational fishing in terms of biomass and impacts on fish stocks. While methods exist to estimate the catch [14–18], in some countries, these estimates can become significantly inaccurate due to potential challenges in engaging with fishers, weighting methods that does not account for seasonal variations in prey availability and fishing trip frequency, and other sources of unreliable estimates [13,19]. European regulations aimed to establish a framework for collecting and utilizing data in all the fisheries, including recreational ones [20]. However, unlike commercial fishing for which data collection is based on field monitoring and time series collection systems [21,22], recreational fishing lacks such a concrete monitoring framework [19,23]. Moreover, studies on the impacts of recreational fishing on fish stocks and fish mortality risk are still limited and often conducted on a local scale, frequently with high levels of uncertainty [19,24,25]. Indeed, while the effects of commercial fishing on fish populations and marine ecosystems have been monitored for decades [26,27], those associated with recreational fishing have been relatively understudied. This disparity is partly due to the perception that the catch by recreational fishing could be considered negligible when compared to the catches by commercial fishing fleets [24,28]: such a perception has likely been influenced by the scientific literature focusing on commercial fishing catches, which has often reported catches of several tens of tons (t) of fish biomass [29], leading to the biased belief that the catch of recreational fishing is significantly smaller in comparison [30–32]. Consequently, most of the recreational fishers who fish in coastal areas today are not monitored. Reliable data about the number of recreational and sportive fishers and their impact on fish stocks are therefore very difficult to obtain, making it even more challenging to evaluate the current catch or assess the impacts on the target species population [33,34].

Despite the difficulty in finding data, there is evidence that recreational fishing has received increased interest. In the Mediterranean area, recreational and sportive fishing is carried out with increasing frequency, targeting a variety of fish species [33,35]. This trend contradicts the fact that recreational fishing does not even require a special permit in some marine and coastal environments. In Italy, for example, there is a mandatory national fishing license that allows for recreational fishing in inland rivers or water bodies, but no license is required in coastal areas [36], although fishers are still required to respect the regulation about the minimum size and maximum daily amount of catch, which is 5 kg [37].

This makes it even more challenging to track the actual characteristics of recreational fishing in the Venice lagoon, the largest Mediterranean coastal lagoon facing the Adriatic Sea. Home to the city of Venice and island settlements, the Venice lagoon represents a complex social–ecological system [38–40] that has undergone centuries of co-evolution based on the reciprocal interactions between ecosystem dynamics and human activities [41]. Local inhabitants have acquired the ability to detect and exploit these seasonal and distributional patterns for artisanal fishing and capture-based aquaculture, which have been thoroughly studied [42–44]. These practices represent the application of the traditional ecological knowledge that has characterized the people of the Venice lagoon for centuries [45]. Conversely, it has not been clearly determined yet whether recreational fishing trends are equally influenced by such factors. Moreover, the vastness of the lagoon and its connection to the sea, reachable with a short boat trip, complicates determining the number of people engaged in recreational fishing. Locals who possess a recreational license might not necessarily fish in the lagoon, but in inland waters and rivers outlets instead, potentially leading to an overestimation if counted among lagoon fishers. Conversely, those without a license may fish just outside the inlets, an area considered marine waters, requiring only communication rather than a license [46], thus evading the counting. These factors make it difficult to obtain accurate insights into recreational fishing activity, unless individuals are interviewed about their fishing habits.

Previous studies focusing on recreational fishing delved into the estimation of the catch per unit effort of the sector, both on the west coast of the Adriatic Sea [16] and in the Venice lagoon [38]. Nevertheless, high uncertainties in the number of recreational fishers active in the Venice lagoon still remain, and to date, the yearly catch is still considered affected by a high degree of uncertainty, posing challenges to estimate the actual patterns of recreational fishing.

To better understand recreational fishing in the Venice lagoon and explore methods for establishing a standardized framework to estimate recreational fishing catches in lagoon and coastal ecosystems, this paper investigates the dynamics of recreational fishing and unravels how fishing habits and fishers' behavior might affect recreational fishing catches. To do so, the main objectives are to estimate the number of recreational fishers that are active on a daily basis in the lagoon, evaluate the annual catch by recreational fishing, and present the implementation of workflows based on remote sensing data that may support effective management rules.

2. Materials and Methods

The Venice lagoon study area is located on the west coast of the Adriatic Sea in Italy (Figure 1). Three inlets connect the lagoon with the Adriatic Sea: Lido inlet (Figure 1A), Malamocco inlet (Figure 1B) and Chioggia inlet (Figure 1C).

The exchange of water as well as organisms is ensured through these inlet channels [47,48] that are also subject to intensive nautical traffic [40,49].

The study aimed to collect information and data about fishers' behavior, and data about recreational fishing spatial and temporal dynamics. Figure 2 illustrates the sources of data and the workflow.

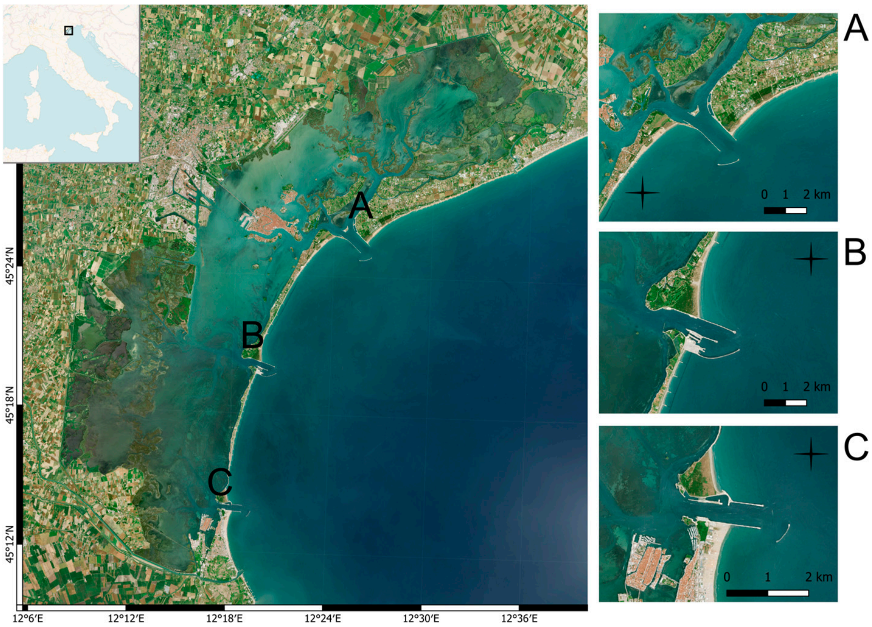

Figure 1. The Venice lagoon and its three inlets: (**A**) Lido inlet, (**B**) Malamocco inlet, and (**C**) Chioggia inlet.

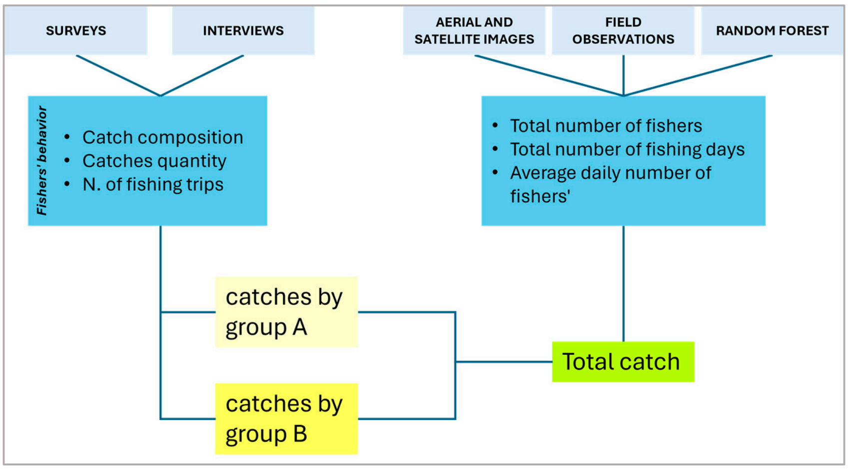

Figure 2. The workflow implemented to gather information and data on both fishers' behavior and fishing activity's spatial and temporal patterns. Group A represents most of the fishers in Venice lagoon, with low fishing trip frequency and low catch. Group B stands for the group of fishers with high catch determined by higher fishing trip frequency and higher success rate.

In the first step, an online questionnaire was addressed to recreational fishers that fish within the Venice lagoon and its inlets. The questionnaire was disseminated online by sharing the link through the website of the Italian Federation of Sport Fishing, Under-water Activities, and Fin Swimming (F.I.P.S.A.S.), as well as through social networks and QR codes in local fishing shops, allowing for snowball sampling [50]. To reach as many fishers as possible, social network groups were selected based on their popularity among local fishers and the availability of site administrators to publish our questionnaire. Additionally, 10 questionnaires were directly sent to specific fishers through a mailing list gathered in a previous exploratory study. All the respondents agreed to the collection of anonymous data by agreeing with the fully informed consent provided at the beginning of the form.

The survey required the participants to list the lagoon areas mostly frequented for fishing activity and the fishing techniques they use. Subsequent questions prompted them to declare the target species and the number of fishing trips dedicated to each target species during different seasons, along with the average catch in kg for each species during each fishing trip. The average success rate in catching fish during the fishing trips was also requested. An additional question asked whether the respondent believed most anglers catch more or less than 5 kg per fishing trip, namely the maximum catch limit per angler. The survey questions are listed in Appendix A. To minimize potential biases and encourage honest reporting, the questionnaire was designed to be anonymous. While there are inherent limitations when asking fishers to estimate their catch and their average success rate, anonymity helps mitigate concerns about overreporting or underreporting [51,52].

Data collected through the questionnaire were aggregated and elaborated to obtain an estimate of fishing trips and catch per year per person. To validate and enhance the data summarization, additional insights were gathered through six interviews with experts. The interview questions mirrored those in the questionnaire, asking about fishing areas, techniques, target species, number of fishing trips per season, and average catch in kg per trip. Additionally, the interviews included extra questions about the respondents' perceptions of the average behavior of other anglers. The interviewees were selected based on their high level of experience and knowledge in recreational fishing; their responses were consistent with the questionnaire data and showed a high level of agreement among themselves, highlighting a reliable and comprehensive understanding of fishing practices.

To quantify the maximum possible number of days in a year that present conditions suitable for navigating and fishing, a random forest (RF) classifier was applied to daily reports of the last year's weather and marine conditions. The model, set up with a 500-tree default parameter [53], considered 5 predictive factors:

- The differentiation between holidays and weekdays;
- The average temperature and daily temperature range;
- The probability of precipitation;
- Wind intensity and direction;
- Tidal patterns.

To understand recreational fishing dynamics in the Venice lagoon, a dual approach was devised in order to differentiate between the total number of recreational fishers who could potentially fish in the lagoon (based on boat counts) and the number of fishers actively engaging in fishing activities on a daily basis (based on real-time observations).

To estimate the total number of recreational fishers, a direct survey was performed to count fishing boats moored in docks, harbors, and mooring spaces in the Venice lagoon. The boats used for recreational fishing in the lagoon are identifiable by their dimensions, shape, hull proportions, and onboard fishing equipment. This method involved conducting a visual census during field visits to 22 harbors to identify such boats and performing photointerpretation of very high-resolution aerial images from 4 and 10 October 2022, which were available via Google Earth Pro desktop version [54]. An example image is provided in Appendix B. Additional information about the number and characteristics of recreational fishers' boats was requested from six dock managers, including details on the length and typical onboard equipment. This approach provided an estimate of the total number of boats potentially used for recreational fishing. The number of such moored boats was used as a proxy to estimate the comprehensive number of people potentially participating in recreational fishing in the Venice lagoon.

On the other hand, the actual count of recreational fishers consistently active on a daily basis was quantified through a series of recurrent 4 h long field trips, involving real-time counting of individuals engaged in fishing activities. These field trips focused specifically on the areas of the three inlets (Figure 1), which were the locations most frequented by fishers as declared in the questionnaire. During each field trip, a structured report was generated, including details such as date and time, wind speed and direction (obtained from meteorological forecast websites), weather and tidal conditions, and the observed number of boats involved in fishing activities. Efforts were made to cover different times of the day and various weather conditions, including late evening and early morning sessions, by planning the field trips to cover all the possible combinations.

The SCP plugin [55] interfaced with the software QGIS 3.22.11 was then used to download and pre-process for atmospheric correction Sentinel-2 multispectral images of the Venice lagoon. Seven Sentinel-2A scenes, acquired on the same days the field trips occurred, were chosen. During these trips, the presence and location of fishing boats were recorded and then imported as a vector-point layer in QGIS. The point locations were overlapped on a natural-color composite multiband image (R, G, B + NIR) of the respective day. The boat positions recorded in the field were confirmed by the detection of pixels appearing as a white pixel; thus, the reflectance values extracted in the point locations enabled the detection of the reflectance range for each spectral band. The NIR band values proved to be the most informative.

Once the reflectance value ranges were assessed based on the images which coincided with the field trips for ground-truth validation, further 15 Sentinel-2 images were retrieved in the period from January to December 2023, two per month, chosen among images gathered in different tidal trend conditions. A filtering algorithm was applied to enhance only the pixels with NIR band reflectance within the ranges associated with pixels containing boats (average NIR reflectance of boats 1253 $\pm$ 142 s.d. nm, contrasting water NIR reflectance 1016 $\pm$ 19 s.d. nm). The stack combination of the NIR band with the blue band reflectance values—multiplied by 1.75—aided in distinguishing fishing boats in the scene. Built-up areas along the coastline were masked by a buffer.

A subsequent manual photointerpretation identified the target objects. Travelling boats, hence not idling for fishing, were distinguished by their elongated wakes and filtered out from the count. Additionally, since field observations in specific zones showed clusters of recreational boats within a very specific area outside of the inlet structure, those boats were conservatively not counted, but the almost exclusive use of certain other areas by fishers was confirmed.

Remote sensing imagery elaboration and geospatial analyses were performed with the open-source software QGIS 3.22.11 [56]. Data aggregation and statistical analysis were performed in R language within the RStudio computational environment [57,58] with R core functions and R packages dplyr, sp, randomForest.

3. Results

The response rate of the questionnaire was estimated to be around 20% of the potentially reached people, namely the number of the social network group followers and the number of email addressees; this was considered an acceptable response rate [59,60]. The sample, n = 170, was composed mostly of male individuals with only two female respondents, with an overall age distribution as follows: 19.4%, age class 18–30; 20.0%, age class 31–40; 23.5%, age class 41–50; 19.4%, age class 51–60; 17.6%, age class > 60.

3.1. Fishers' Behavior and Catch Estimates

According to the questionnaire answers and interviews, the most targeted species are the seabream (*Sparus aurata*), seabass (*Dicentrarchus labrax*) and cuttlefish (*Sepia officinalis*). All the participants declared to use fishing rods with reels, implementing different fishing techniques (e.g., edging, trolling, bottom fishing). Fishing equipment and the casting and fishing technique are chosen based on the target species; therefore, each fishing trip is usually devoted to catch one specific target species due to lure and bait specialization that might differ considerably based on the fish-feeding habits and the season. For instance, a fishing trip devoted to targeting seabass would implement techniques like spinning, and ledgering with live baits such as other lagoon fish and crustaceans. Conversely, seabream is more frequently fished with marine invertebrates such as mussels and bait worms by ground fishing or float fishing.

The questionnaire revealed that the frequency with which each fisher engages in a fishing trip is highly variable depending on the fisher's choices and personal preferences. In fact, despite the random forest model, which was run on the weather, and tidal trends which detected at least 160 days/y, presenting suitable conditions for fishing, the results showed that the fishing frequency is strictly related to the seasonality and willingness to target a particular species of fish (Figure 3).

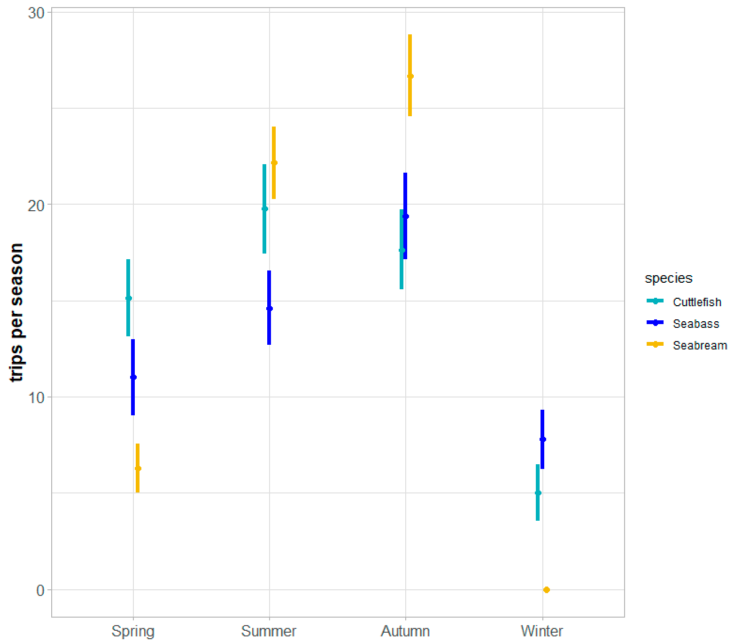

Figure 3. Number of fishing trips per season that each fisher, on average, dedicate to target species. Points represent the mean value; bars represent the standard error.

Moreover, the answers and the information collected through satellite images revealed that the days of the week are not exploited equally by all the participants, with a preference for weekdays for some fishers, whereas others prefer to go fishing during weekends and festivities. The average catch per person in each fishing trip, per species, was then calculated. Results showed that the *Sparus aurata* catch was on average 2.81 kg; for *Dicentrarchus labrax*, 2.5 kg; and for *Sepia officinalis*, 3 kg. However, high variability was reported, and 39% of the respondents stated that, in their opinions, many fishers consistently catch fish well above the 5 kg limit. This suggests that the responses may be influenced by a potential bias, stemming from reluctance to admit that they sometimes make catches exceeding the limits prescribed by recreational fishing regulations.

Considering all this, two different types of fishers' behavior emerge:

- The first group (group A) are characterized by a frequency of fishing trips ≤ 4 per month which occur mainly during the weekends. They declare having a mid–low success rate, namely 0.71 on seabream, 0.14 on seabass, and 0.58 on cuttlefish, and a low catch per person per fishing trip.
- The second group (group B) are characterized by a frequency of trips higher than 15 per month (median = 20 trips per month, more frequently on weekdays) that are near the potential 102 days per fishing season, when there are optimal conditions for fishing, as detected by the random forest model informed with weather and marine conditions. This group consistently reports high catches and a high success rate, namely 0.9 on seabream, 0.7 on seabass, and 0.9 on cuttlefish.

While group A represents almost 90% of the recreational fishers, group B is less numerous and, according to the interviews, accounts for approximately 7% of the active recreational fishers in the Venice lagoon. The collected information helped refine the estimation of the catch; the results were very different between the two groups due to the substantial differences in behavior. Considering the sum of the average number of boats observed in the three inlets as the estimate of recreational fishing daily effort, the total catches resulted in 18649 kg/y of seabream, 15817 kg/y of seabass, and 8356 kg/y of cuttlefish. Of this total amount of catch, the majority was caught by group B (Figure 4).

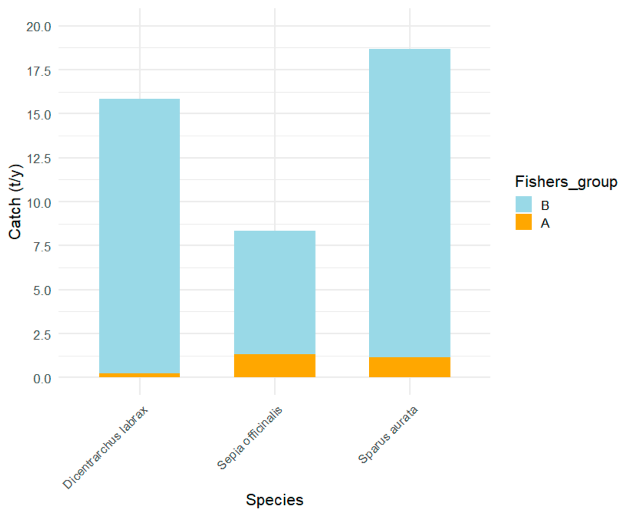

Figure 4. Yearly catch estimate based on the questionnaire data. The catch is distinguished for each of the two groups of fishers.

3.2. Fishing Boats and Aggregational Patterns

According to the observations collected through observation campaigns and photointerpretations of the images available via Google Earth Pro, the best estimation of the number of boats moored in the Venice lagoon suitable and equipped for recreational fishing was ~980 units boats. Such a count was validated by the estimations of the interviewed people.

However, field observations and analyzed satellite images unravel that, even on days with optimal tidal and weather conditions, the number of boats engaged in fishing typically ranges from 10 to 40 (mean value 22 ± 14.2 SD, median 15). In particular, the number of boats is capped to a certain maximum per day, specifically 31 for the Malamocco inlet and 38 for Chioggia and Lido inlets, with occasional exceptions during summertime when the maximum number reaches 45 boats at the Lido inlet. Through the analysis of satellite data, combined with field observations, a map of the distribution of boats engaged in recreational fishing for each inlet was also obtained. Figure 5 shows the most frequently visited areas.

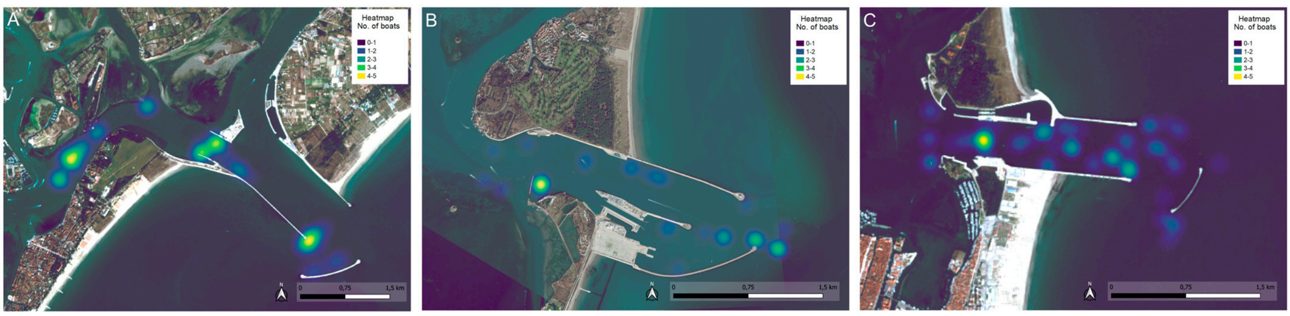

Figure 5. Distribution of fishing boats in the three inlets, as gathered from satellite data analyses. The higher the color, the more frequent the observations of boats engaged in fishing. (**A**) Lido inlet, (**B**) Malamocco inlet, and (**C**) Chioggia inlet.

Each of the three areas within and around the inlet presents some hotspots. Additionally, the numerosity of fishing boats were not equally distributed among the three inlets. The Lido inlet (Figure 5A) presented, in almost all the surveyed days, the maximum values of fishing boats concentrated in three points where their number was consistently twice as many than in the other inlets. In the Malamocco inlet (Figure 5B), seven hotspots were detected, whereas the Chioggia inlet (Figure 5C) presented a scattered distribution throughout the water surface, with a hotspot in the inner lagoon side.

3.3. Comparison with Catch by Commercial Fishing

During 2023, the fish markets of Venice and Chioggia recorded landings of a total of 108.67 t of seabream, 15.71 t of seabass, and 436.98 t of cuttlefish [61–63].

Although considering the most conservative estimates, recreational fishing in the Venice lagoon accounted for approximately 2% of the catch of cuttlefish and 17% of the catch of seabream with respect to the professional fishing catch. On the contrary, the catch of seabass by recreational fishing is similar to the professional fishing catch (15.8 t and 15.7 t per year).

4. Discussion

Recreational fishing in coastal areas is practiced by thousands of people on European coastal waters [15,44]. Due to its widespread and steadily increasing popularity [3], it is important to characterize the activity patterns, especially on coastal areas, to ensure a good management of natural resources and reduce unsustainability. Studies and research are required to evaluate the possible impact of recreational fishing on fish stocks, along with the detection of possible conflicts that may arise with commercial fishing and conservation purposes. However, the evaluation of the catches by recreational fishing is still a challenging task because the fishing patterns and impacts result from the synergies of the behavior of different individuals and the ecosystem characteristics. Being part of an adaptive complex system, all these factors are not always consistent and depend on various conditions, which are never entirely predictable [17,35]. Achieving accurate estimation of the recreational fishing catch is therefore highly dependent on several data that, unfortunately, are often lacking. Even when considering that each fisher typically catches a certain average amount of fish biomass, the uncertainty about the number of fishers active on coastal seas and coastal lagoons might undermine the opportunity to obtain a realistic result.

In Italy, efforts have been made to census the number of persons that fish at sea in the Italian territorial waters through a registration portal [46]. Yet, as our results showed, the estimation of the catch cannot rely only on the total number of fishing licenses, or merely on the number of fishing boats, but also need to consider the behavior of fishers. As highlighted in this study case, the difficulty of assessing the catch from recreational fishing is particularly true for the Venice lagoon, where the impact of recreational fishing has remained unassessed for a long time. Despite a comprehensive regulatory framework for all the types of fishing activities at the national level [64], at the regional and local level the laws aim to regulate the multifaceted context of fishing in riverine, transitional and maritime waters [65,66]. However, monitoring and enforcing the rules for recreational fishing are still significant challenges.

From a morphological and ecological perspective, a distinctive feature of the Venice lagoon is that the inlets connecting it to the Adriatic Sea serve as passages not only for water but also for fish that perform their migrations through these channels [67,68]. These geomorphological features, along with the bathymetric landscape of the seafloor [69], also guide fish in their daily and periodic movements. The seasonal trend in the number of fishing trips, as declared through the questionnaire and validated with field observations, clearly reflects the knowledge acquired by recreational fishers about fish migratory dynamics and favorable environmental conditions. The results indeed showed that individuals choose when to go fishing based on tidal and weather conditions, with the aim to maximize the success rate. Nevertheless, in this case, behavioral factors also influence the fishing dynamics; the tide is the most important variable for fishers who fish on weekdays, but it has been observed that for the group that fish on weekends, the most important factor is related to weather conditions, often ignoring what could be the best tidal conditions. This may suggest that this group tends to prioritize the comfort of the boat trips and the relaxation of the fishing experience, rather than finding ideal environmental conditions to maximize the catch, thus explaining the different success rate and catches.

The spatial distribution of boats engaged in fishing activity testifies to an aggregational pattern matching with some areas that are characterized by a significantly higher quantity of fish. If considering the distribution of fish fauna, expressed as the number of observed targets retrieved during a series of recently conducted echo-sounding campaigns [48], the distributional pattern of boats engaged in fishing activity is remarkably similar to the distributional pattern of the fish fauna and the biomass hotspots. This discloses that not only professional fishers and aquaculture operators but also recreational fishers have learned to notice and exploit the characteristics of the Venice lagoon ecosystem dynamics, leveraging on the knowledge they have empirically acquired through personal observations and information shared with other fishers. Such traditional ecological knowledge of the local ecosystem dynamics has shaped, for a long time, the co-evolution of the Venice social–ecological system; now, this heritage is influencing the activity of recreational fishing in terms of spatial and temporal patterns, as well as specialized fishing techniques for the target species.

A consequence of this empirical knowledge is also seen in the different catches on target species. Indeed, fishers report satisfactory success rates in at least half of the trips dedicated to seabream and cuttlefish; conversely, the success rate in catching seabass is lower and generally achieved almost exclusively by experienced and dedicated fishers of group B. This is likely due to the seabass behavior, which is not easily predictable, requiring frequent fishing trips to succeed in intercepting this elusive predator.

Additionally, the spatial distribution of fishers unravels the presence of a social driver rather than an ecological one. For instance, the number of fishing boats observed in the Lido inlet was consistently twice as many as those observed in the other inlets. The reason for such a distribution is the proximity of the Lido inlet to the historic center and the most populated islands of the Venice Lagoon, making it easily accessible to a significantly larger number of fishers compared to the other two inlets. The combined pattern of spatial and temporal distribution suggests that, in the highly frequented area of the inlets, there is competition for space among recreational fishers. This pattern reflects, on one hand, the spontaneous respect for a sort of tacit rule defining the minimum acceptable distance between boats engaged in fishing, and on the other hand, the presence of an emerging behavior that sees different people fishing on different days, as if it was an activity occurring on a "periodical" basis. In such a context, the assessment of the average daily number of recreational fishers that are active in a certain area, as proposed in this study, represents a novelty which is capable of increasing the accuracy of the estimates, overcoming the possible biases introduced with the attempt to indiscriminately assign the same average catch per trip, and the same fishing frequency, to each fisher that is potentially interested.

While the estimated yearly catch for group A is aligned with the one estimated by previous studies [16,17], the present study also unraveled that fishers have very different behavior. Here, we could clearly identify two classes of fishers, each characterized by different expertise, efficiency, preferences and frequency in fishing trips. Although more than the two subclasses might be present along the wide spectrum of behavioral trends, the novel introduction of this dichotomy provides new information that has never been considered before in recreational fishing impact assessments and is of particular importance in dynamical social–ecological systems. Our results showed a significant disproportion between the biomass caught by the different groups of fishers; for example, regarding seabream and cuttlefish, the quantities caught by group B are at least five times those caught by group A. This disproportion is even more pronounced regarding seabass fishing. Therefore, if the catch of group A is noticeable but not highly impactful, the catch of group B is more consistent, and worth being considered and thoroughly analyzed in the context of the lagoon ecosystem.

In light of these findings, recreational fishing practiced by individuals with a behavioral profile characterized by very high frequency and efficiency in catch rate could potentially compete with artisanal fishing. This impact would be further intensified when considering that the estimated total number of fishers potentially interested in fishing, based on the presence of the 980 boats hosted in docks and moorings, could result in a total catch approaching 200 t per year if they were all active with the same frequency and efficiency. Currently, the presence of competition for space makes it impossible to have all the fishers contemporarily engaged in fishing at the very same moment; however, the hypothesis of them behaving in the same pattern detected in this study would lead to an unsustainable scenario. This is also confirmed by other studies [70] that also suggest recreational catches could account for approximately 30–45% of landings of small-scale local fishing [71].

In the Venice lagoon, such competition is exerted not only in terms of catch and impact on fish stocks, but also based on spatial distribution. Not only should the inlets not be considered as fishing grounds due to the necessity to ensure navigational safety [72], but recreational fishers also often exploit both lagoon and coastal marine areas that are of great interest to artisanal fishing fleets. The cryptic nature of poaching, along with the low compliance of people potentially practicing such detrimental behavior, represents additional challenges and adds other factors of uncertainty worthy of being taken into account [73,74].

All of these findings generate reciprocal discontent that might not be openly declared but is highly perceived among the operators in commercial fishing. There is indeed the risk that professional fishers, due to the difficulty in distinguishing between recreational fishers who fish only for recreational purposes and those who consistently catch significant amounts of fish, express their discomfort towards the entire category or recreational fishers, in a negative social feedback loop that is difficult to disentangle. Artisanal fishing operators, belonging to a sector that has been struggling for some time due to the decline in fish species [75,76], often feel threatened by several external factors [77]. Among these, the competition with recreational fishing features prominently, especially in cases where there is suspicion that a part of the recreational fishers actually sell their catch, which can lead to unfair competition in the market.

Indeed, it cannot be ruled out that, if the same dynamics of high-efficiency recreational fishing persist without equally efficient monitoring, a sort of market supporting profit-driven fishing may emerge. Similar situations have indeed occurred in other coastal areas of the Mediterranean [78,79], leading to an intensified moral conflict between operators in commercial fishing and recreational fishing [80], and creating a cycle that encourages this type of irregular activity, making its ecological effects comparable to commercial fishing fleets. While this may be just a hypothetical risk, verifying it and informing governance through studies capable of describing not only ecological dynamics but also social consequences are equally important to ensure the sustainability of the uses of the lagoon and the sea.

On the other hand, the law enforcement bodies responsible for coastal marine surveillance in the study area are currently not always available to thoroughly monitor all the boats and the catches by recreational fishing. Therefore, the implementation of a periodic monitoring program based on the days detected by an algorithm, such as the RF used in this work, along with the monitoring from remote sensing technologies, could enhance our understanding of the recreational fishing dynamics. Moreover, since the aggregation pattern of fish species and their seasonal migrations have shown to drive fishing activity, there is the possibility to use the methods presented in this study to build promising ecological models that, by predicting the distribution of recreational fishers and their behavioral patterns, could effectively help monitor and manage them [81].

Despite the advantages, the limitations of the methods must be taken into careful consideration. First of all, the presence of recreational fishers who do not use a boat but cast from the beach and the piers along the inlets cannot being tracked with remote sensing technologies. However, as observed in a previous study [38], those are a minority, and huge catches are hard to achieve by them. To cope with this aspect, a good method would be implementing systems to accurately count active recreational fishers and monitor the catches through institutional databases and smartphone applications, as suggested by other authors [82,83]. This might also be useful to increase the self-discipline of fishers and minimize poaching activities, if not with a direct contrasting approach, through the empowerment of earnest fishers and the decreased social acceptability of an excessive catch or illegal behavior.

In all of this, it would be ideal to promote participatory processes and decision-making forums that leverage on the sense of stewardship of all the people that frequent the sea. In those contexts, fishers from the two categories can define shared approaches and bottom–up initiatives, participating with the decision makers in the governance process to ensure peaceful enjoyment as well as fair and sustainable use of marine resources.

5. Conclusions

Analyzing recreational fishing is a complex task, since the pattern of the activity is not only dependent on the environmental features and ecological factors of the ecosystem, but also on community dynamics and the behavior of fishers that overall constitute an adaptive system with reciprocal counteractions.

Recreational fishing in the Venice lagoon represents an emblematic case of such a system where the synergy of ecosystem characteristics, behavioral factors, and traditional ecological knowledge generates a complex outcome. In this case study, the best possible estimate has been proposed based on available data. However, some uncertainties persist that are not easily overcome but through a systematic effort towards accurate and regular monitoring and control over time.

The novelty of our approach lies in conducting satellite-based monitoring and experimenting with advanced technologies to test the possibility of studying recreational fishing on a small spatial scale in the Venice lagoon and in other coastal areas as well. This has revealed potential unbalance in recreational fishing effort among different groups, each characterized by different fishing trips' frequency and catch. The possible presence of other categories and subcategories could add complexity to the already complex picture that emerges, underscoring the importance of considering not only ecological data but also seasonal trends, inter-year variability, and data pertaining to social behavior. Our results suggest that, in coastal areas, it is necessary to consider both ecological relationships and individual behavior to understand the true impact of recreational fishing. This effort appears extremely necessary in light of responding to the recommendation issued by the General Fisheries Commission for the Mediterranean of the FAO (GFCM/45/2022/12), which encourages Mediterranean States to define a minimum set of rules for sustainable recreational fishing in the Mediterranean Sea. However, in this process, it is evident on one hand that there is a need to create a good system as soon as possible that can carry out the necessary checks to enforce the laws, and on the other hand, that appropriate social analyses across sectors should be included in order to create and facilitate bottom–up dialogue and regulations. Leveraging the adoption of pro-environmental behaviors by all actors, along with the sharing of knowledge and experiences, could be one of the methods to avoid unsustainable catches caused by a few individuals. This approach would allow everyone to feel part of the sea and coastal areas they frequent and derive benefits from, whether they are economic resources, sustenance, or invigorating experiences.

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Data Availability Statement: Data collected for this study are available upon reasonable request.

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Appendix A

IT

- Quali sono i metodi di pesca che preferisci?
  - Canna da pesca
  - Pesca subacquea/apnea
  - Altro ____________________
- Quanto spesso ti rechi a pescare, mediamente?

	1 volta al mese	2 volte al mese	1 volta a settimana	2 volte a settimana	>2 volte a settimana
Primavera					
Estate					
Autunno					
Inverno					

- In quali aree vai a pescare di solito?

Scelta multipla con mappe

- Solitamente peschi dalla barca o da terra?
- Quali specie peschi? In media, quanto pesce trattieni per ciascuna specie pescata, per ogni uscita di pesca?

Specie	Peso trattenuto per uscita di pesca
1 ________	
2 ________	
3 ________	
n ________	

- Quante uscite dedichi a ciascuna specie, per stagione?

Specie	Primavera	Estate	Autunno	Inverno
1 ________				
2 ________				
3 ________				
n ________				

- Considerando il totale di uscite a pesca che effettui in media, quante di queste hanno successo e ti fanno realizzare tali catture?
- Secondo te, in media, i pescatori ricreativi trattengono più o meno di 5 kg di pescato?
  - La maggior parte trattiene meno di 5 kg
  - La maggior parte trattiene più di 5 kg
  - Non so
  - Altro ____________________________

EN

- What are your preferred fishing methods?
  - Fishing rod
  - Spearfishing/diving
  - Other ______________________
- How often do you go fishing on average?

	1 time per month	2 times per month	1 time per week	2 times per week	>2 times per week
Spring					
Summer					
Autumn					
Winter					

- In which areas do you usually go fishing?

Multiple choice on maps

- Do you usually fish from a boat or from the shore?
- Which species do you target? On average, how much fish do you retain for each species caught on each fishing trip?

Species	Weight per fishing trip
1 ________	
2 ________	
3 ________	
n ________	

- How many fishing trips do you devote to each species, per season?

Species	Spring	Summer	Autumn	Winter
1 ________				
2 ________				
3 ________				
n ________				

- Considering the total number of fishing trips you typically take, how many of these are successful in bringing catches?
- In your opinion, on average, do recreational fishers retain more or less than 5 kg of catch?
  - Most retain less than 5 kg
  - Most retain more than 5 kg
  - I don't know
  - Other ____________________________

Figure A1. Questions included in the survey addressed to fishers.

Appendix B

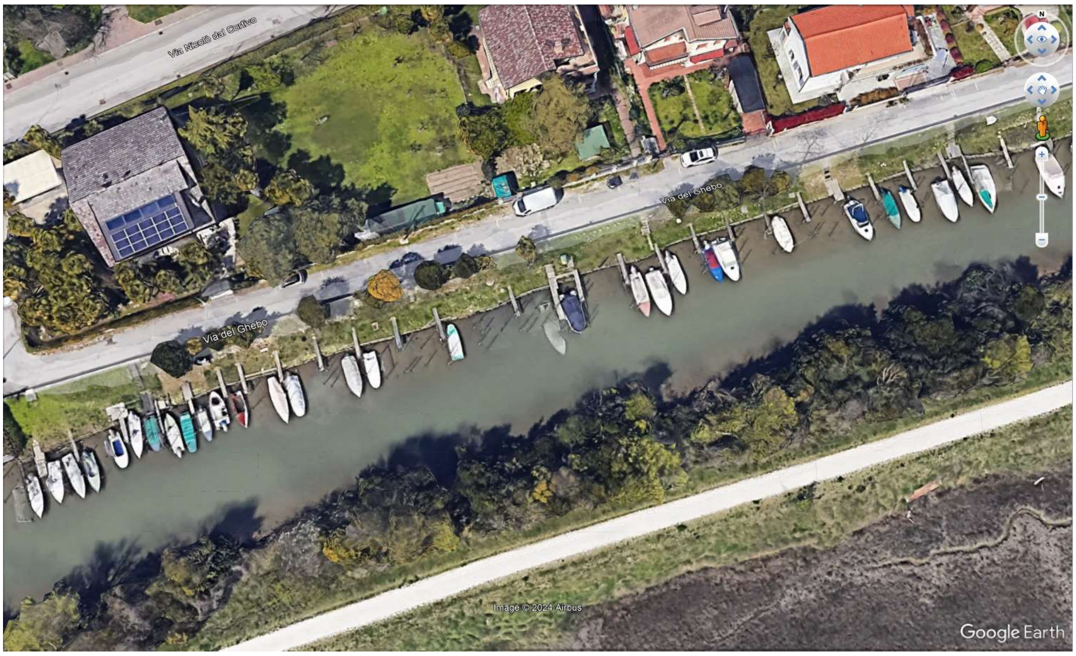

Figure A2. Example of a high-resolution image used for identifying and counting moored boats. Source of the image: Google Earth Pro, desktop version (2023).

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