

Documenting the spatial and temporal expansion of grouper species in the eastern Adriatic Sea (Croatia) through local ecological knowledge of recreational fishermen

Prostorno i vremensko širenje kirnji u istočnom Jadranskom moru (Hrvatska) dokumentirano istraživanjem lokalnog ekološkog znanja rekreacijskih ribolovaca

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Abstract

Groupers are important predatory marine fish species, and also economically important to commercial and recreational fisheries, but threatened by overfishing worldwide. The dusky grouper (*Epinephelus marginatus*) is the most common species that historically occurred in the Southern and central Eastern Adriatic, while other species were mostly restricted to the southern part of the region or were not recorded in the Adriatic Sea. However, the warming of the sea caused by recent climate change has caused some grouper species in the Eastern Adriatic to expand northward. This spread has been poorly documented, largely because rocky coastal habitats, which are less accessible to conventional research methods that often rely on specific fishing gears, have received far less attention than other more accessible habitats i.e. soft bottoms. Reports of recent grouper expansion are primarily anecdotal and mainly based on the extensive observations of recreational fishermen who mainly utilize rocky coastal habitats. In order to gain insight into this phenomenon, we conducted a survey to investigate the distribution of groupers along the Croatian coast of the eastern Adriatic using the Local Ecological Knowledge methodology. Semi-structured interviews were carried out to record fishers' knowledge and perceptions of changes in their catches, as well as personal observations. The data collected provided information on the spatial and temporal expansion of groupers in the eastern Adriatic over the last 60 years, as perceived by local recreational fishermen.

Sažetak

*Kirnje su važne predatorske vrste morskih riba, isto tako ekonomski važne u gospodarskom i rekreacijskom ribolovu, ali i ugrožene pretjeranim izlovom diljem svijeta. Kirnja golema (*Epinephelus marginatus*) je vrsta koja je povijesno nastanjivala južna i srednja područja istočnog dijela Jadrana, dok su ostale vrste uglavnom bile ograničene na jug ili nisu bile zabilježene u Jadranskom moru. Međutim, zagrijavanje mora uzrokovano klimatskim promjenama omogućilo je širenje staništa kirnji prema sjeveru. Ovo širenje je do sada bilo slabo dokumentirano zato što su stjenovita obalna staništa, koja su manje dostupna konvencionalnim metodama istraživanja koje se često oslanjaju na specifične ribolovne alate, manje istraživana od drugih pristupačnijih staništa, npr. mekog dna. Dobiveni rezultati o nedavnom širenju kirnji prvenstveno su anegdotalni i uglavnom se temelje na zapažanjima rekreacijskih ribolovaca koji u ribolovu koriste stjenovita obalna područja. Kako bismo stekli uvid u ovaj fenomen, proveli smo istraživanje rasprostranjenosti kirnji duž hrvatske obale istočnog Jadrana metodologijom lokalnog ekološkog znanja. Provedeni su polustrukturirani intervjui kako bi se zabilježilo znanje ribolovaca i percepcija promjena u njihovim ulovima, odnosno njihovim osobnim zapažanjima. Prikupljeni podaci dali su informacije o prostornom i vremenskom širenju kirnji u istočnom Jadranu u posljednjih 60 godina, prema percepciji rekreacijskih ribolovaca.*

KEY WORDS

northward expansion
meridionalization
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recreational fishery
thermophilic native species

KLJUČNE RIJEČI

širenje prema sjeveru
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termofilne autohtone vrste

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1. INTRODUCTION

The groupers belonging to the Serranidae family are a relatively large group of teleost fishes. Up to now, 17 species have been reported from the Mediterranean Sea [1], of which 6 are known from the Adriatic Sea [2]. Two genera are present in the Adriatic, namely *Mycteroperca* Gill, 1862 with a single species *Mycteroperca rubra* (Bloch, 1793), and *Epinephelus* Bloch, 1793 with 5 species, *Epinephelus aeneus* (Geoffroy Saint-Hilaire, 1817), *Epinephelus caninus* (Valenciennes, 1843), *Epinephelus coioides* (Hamilton, 1822), *Epinephelus costae* (Steindachner, 1878), and *Epinephelus marginatus* (Lowe, 1834). The Indo-Pacific *Epinephelus coioides* is the only non-indigenous grouper species in the Adriatic represented by a single record, which considers a specimen caught in the Gulf of Trieste, northern Italy, in 1998 [3]. Groupers ("Kirnje" in Croatian) is the common name for fishes of the subfamily Epinephelinae but is also used colloquially for *Polyprion americanus* (Bloch & Schneider, 1801) of the family Polyprionidae [2]. Groupers are long-lived, slow-growing fish with low natural mortality [4]. However, due to their complex reproductive strategy (i.e., sequential hermaphroditism) and the fact that they inhabit relatively shallow coastal waters, they are particularly vulnerable to overfishing, especially by recreational fisheries [5]. Data on grouper fisheries are largely lacking in Croatia, while the biology of some species has been studied in the past [6]. In Croatian waters, a size limit of 45 cm applies to all grouper species, and since 1996, a seasonal fishing ban on groupers (*Epinephelus* spp.) has been imposed in July and August, during the spawning season [7]. Groupers in the Adriatic Sea are mainly targeted by recreational fishermen, mainly spearfishers, and are considered trophy fish. It is much less represented in commercial fisheries, where it is occasionally caught mainly with set nets and longlines.

Although groupers can be caught with a variety of gear types, most of which are used in recreational fisheries, spearfishing is generally considered to have the greatest impact on grouper populations [8], and therefore it is a sound assumption that a wealth of knowledge about grouper behaviour and relative abundance could be obtained by spearfishers. Since data collection in recreational fisheries is not yet established in Croatia, and targeted field studies aimed at monitoring groupers are usually limited in time and space, a survey of local ecological knowledge (LEK) of recreational fishermen represents a valuable method to describe decadal changes in quantitative and qualitative trends of Adriatic groupers. This information could be used to identify potential conservation measures and management strategies to help protect and conserve the Adriatic groupers populations. However, LEK should be combined with other forms of data collection, such as scientific surveys and monitoring programs, to ensure a more comprehensive understanding of ecological systems and inform effective management decisions.

2. MATERIALS AND METHODS

Data were collected through face-to-face and phone interviews with participants who were mainly established and experienced spearfishers but also with other recreational fishers, such as anglers and long liners, as well as scuba divers. Participants from the whole Croatian coast were interviewed during the period from February 2020 to September 2022. Although spearfishers were the primary target group for this study, we

expanded it to include other types of fishing to try to obtain information on groupers living in deeper habitats. Additionally, in order to expand the knowledge on groupers along the Croatian coastline, we reviewed available scientific literature, books, archives of local newspapers (daily journal *Slobodna Dalmacija*), fishing magazines, and social network groups where recreational fishermen from all over Croatia have actively participated.

To allow for a more open discussion on the topic, the interview did not follow a strictly structured questionnaire, but rather a specific set of questions were asked during the interview in a form of semi-structured interview. Due to the nature of the questions, the data was qualitative in nature rather than quantitative. As a result, a statistically sound approach could not be devised to conduct in-depth data analysis. Instead, a descriptive approach was chosen to elaborate on the results of the survey.

Participants were asked the following set of questions:

- When did you start fishing?
 - Can you tell the difference between the different types of groupers?
 - Where have you caught or observed certain grouper species in a given decade, and where have you not seen them in a given area and decade?
 - What is your perception of the size range, distributional range and population trends on specific grouper species?
 - Are there any anecdotal stories that relate to interesting grouper catches or observations i.e. relating to size, new species, or distributional outliers?
 - Other questions relating to behaviour of groupers.
- Literature sources were selected as references to determine the state of knowledge about the historical distribution of groupers [6, 9, 10]. In order to categorize the abundances occasionally reported by fishermen in the vernacular, we established the following categories:
- Single record: single grouper sightings reported by one or more individuals at a single location and time.
 - Uncommon: groupers sighted twice or more by 5 or fewer individuals in a given area and time period. Fishermen could use terms such as "seen here and there" or "sometimes" to describe this level of frequency.
 - Common: groupers whose presence was confirmed by at least 5 respondents. Fishermen could use terms such as "many" or "plentiful" to describe this level of abundance.

Using these categories, we created general distribution maps for each species surveyed for a given period. Namely, we defined distributional limits for each species, time period and area on the basis of the northernmost limit of particular category. For example, if at least five respondents mentioned that specific species of grouper were present in certain area and year in fewer numbers, we considered that particular species as uncommon southward until the first next area where the species was perceived as common by at least five respondents. However, if such area was preceded in the south with the area of absence, we isolated such areas as outliers (for example Fig 3. 1996-2005). In cases when single records inside the area of absence were reported, such records were represented by red dots. Additionally, distributional limits of particular species from literature sources mentioned previously were used to draw the baseline maps for each species.

The maps show the selected time periods when the changes occurred and the distribution of groupers at the end of each period as perceived by recreational fishermen.

Maps mostly rely on the common division of the Adriatic Sea i.e. into three geographical sub-regions: The Northern Adriatic, the Middle Adriatic and the Southern Adriatic, which differ by their bathymetric and hydrographic characteristics [9]. However, various delineations on the maps were made in regard to the perception of fishermen. For example, if a particular species in a particular period has been observed only on the south side of the island, while the absence of the species was indicated on its northern side, more precise delineation was made (for example in Fig 4. 1996-2005 fishermen mentioned presence on the south side of Korčula island and absence on its northern side). The territory of the Republic of Croatia, which is only a part of the entire sea, extends to all three mentioned sub-regions. This division is additionally indicated in the description of the sites in the discussion.

3. RESULTS AND DISCUSSION

A total of 111 participants engaged in the survey. Of these, 95 practiced spearfishing, 14 used angling techniques or longline, and 14 of them regularly dived using scuba gear in areas considered as suitable habitats for groupers. A total of 60 participants took part in a spearfishing competition at least once. From the total number of spearfishermen, 4 started diving and fishing before 1965, 6 in the period between 1965 and 1970, 4 in the period between 1970 and 1975, 8 in the period between 1975 and 1980, 6 in the period between 1980 and 1985, 9 in the period between 1985 and 1990, and the rest after 1990. Only 5 spearfishers who participated in the survey do not practice fishing today, but they were able to provide information about the time when they were active. The oldest angler started fishing between 1985 and 1990, the others all started later. Among scuba divers, 3 dived in the 1970s, 2 began their careers in the 1980s, and the others later.

For the two species examined in this study, *E. caninus* and *P. americanus*, we did not detect any changes in their distribution over time, possibly due to the fact that they are deep-sea species [2]. In the Adriatic, the depth gradually decreases from south to north [9]. Only in the south and middle Adriatic Sea the depths are suitable for adult *E. caninus*, where it is sporadically encountered nowadays. Therefore, due to its habitat preference, the possibility of the northward spreading of this species is limited by the shallow northern Adriatic. Although subadult specimens of *E. caninus* are often caught in shallow waters, the largest specimen reported by spearfishers weighed less than 10 kg. Most specimens reported by spearfishers were individuals of up to 3 kg. The northernmost occurrence of such a small *E. caninus* was on the Kornati Islands judging by a photo of a specimen that was posted on a social network group in 2017. In contrast to the subadult fish reported to be regularly caught by spearfishermen, anglers and scuba divers reported catches and sightings of adult specimens of this species.

Atlantic wreckfish, *P. americanus*, characterized by an extended pelagic juvenile phase, can be found throughout the Adriatic Sea [11]. With age, this species migrates to deeper waters. Large and adult specimens have been caught only in the southern Adriatic basin [2]. Apart from these two mentioned species, the other groupers of the Adriatic Sea have significantly

changed their distribution and abundance towards the northern regions, a phenomenon already observed in other fish species [12].

3.1. Dusky grouper - *Epinephelus marginatus*

Dusky grouper inhabits almost exclusively rocky bottoms, from shallow waters down to 200 m depth [13]. Although this species has a positive relationship between depth and size, individuals within each age group show a broad depth distribution that appears to be related to the availability of suitable habitat rather than depth itself, as observed in populations in protected areas where the species has recolonized shallow waters [13, 14, 15]. The depth is a limiting factor in spearfishing as most activities occur in shallow water, with only well-trained individuals regularly diving more than 30 meters deep. The deepest known catch of dusky grouper while spearfishing was from 64.2 meters [16]. At least 4 of our respondents have caught it at depths of over 40 meters.

All respondents active in the 70s and 80s agreed that the dusky grouper (bigger than 4 kg) was a common and relatively abundant species in the southern part of the Adriatic. North of the island of Drvenik Mali (middle Adriatic) it was less common and not evenly distributed. In some places, the populations were denser, especially on the southern sides of the islands farthest from the coast. According to the literature, in the given period dusky groupers could be found as far as the island of Premuda which borders the middle and northern Adriatic sub-regions [10]. On some occasions, dusky groupers were caught in spearfishing competitions in Mali Lošinj and on the islands of Srakane (north Adriatic) [17]. North of Lošinj, in the channels of Kvarner and Velebit bays, and on the west coast of Istria, it was unknown or, according to fishermen, very rare. Only one story was known to our respondents in the early 1970s in which a dusky grouper was caught on the island of Rab, which may indicate its occasional occurrence in the northern Adriatic.

It should be noted that in the 1970s and 1980s, there were experienced and renowned spearfishermen whose deep diving abilities enabled them to catch or observe dusky groupers at greater depths [17] but they could not recall seeing dusky groupers north of Lošinj island nor hearing stories about their occurrence in the mentioned area from other spearfishermen. According to respondent reports, the year 1986 marked the first sightings and catches of dusky grouper in Kvarner waters, particularly in the vicinity of Brseč in the northern Adriatic. In the period from the late 1980s to the mid-1990s, only two dusky groupers were reported in the Kvarner and Velebit bays. There were no observations of adult dusky groupers from the west coast of Istria until 1997 when a grouper weighing 4 kg was caught near Umag.

Respondents reported that sightings of dusky groupers started to occur in the Kvarner area, Velebit Bay, and western Istria (northern Adriatic) at the beginning of the 2000s. One dusky grouper of about 5 kg was caught at the pier of Trieste in the early 2000s and was reported by 4 of our respondents. The first dusky groupers that appeared in the bay of Kvarner and Velebit channel had a weight of 3 to 8 kg, and larger specimens were reported later over time. After 2010, dusky groupers became more common in all mentioned areas (Fig 1).

All of our respondents, who have been fishing in the given period, indicated that the first half of the 1990s was a period of

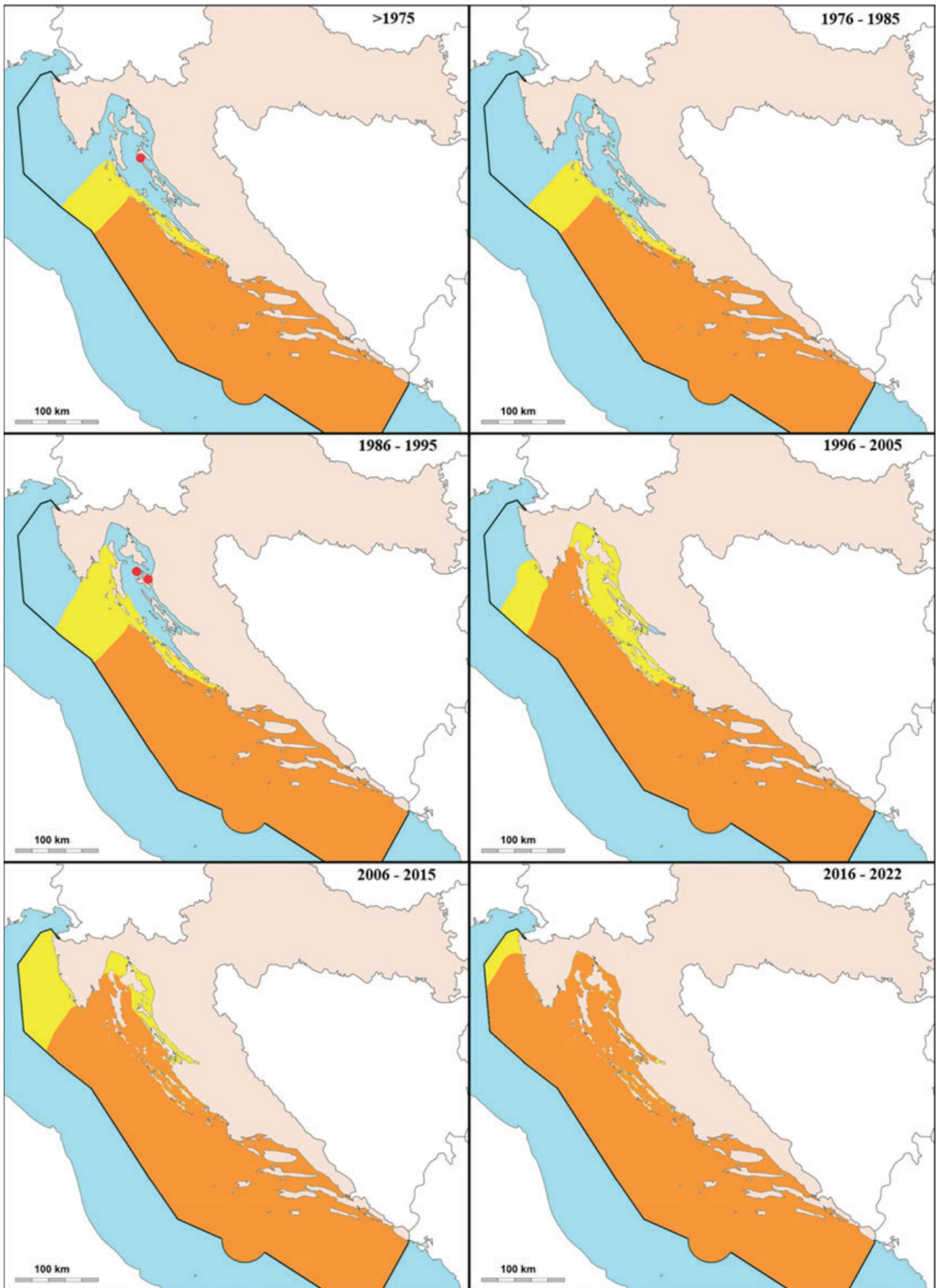


Figure 1 Assumed distribution of dusky grouper *Epinephelus marginatus* on the basis of a perception of recreational fishermen for different periods. Red dots represent single records, yellow represents areas where the species was regarded as uncommon, and orange is where it was regarded as common.

recovery of fish stocks due to a decline in fishing activities as a result of the Croatian War of Independence. In some areas in the south, it was not possible to fish at all. The Prevlaka peninsula UN observer mission was disbanded in December of 2002, after practically functioning as a no-fishing zone for more than a decade. The grouper population was very abundant even in shallow waters (personal observation). Closed areas held by the military during Yugoslavia also functioned as no-fishing zones. One of the examples mentioned by older respondents was the place Marinča Rat on the island of Šolta where, after the withdrawal of the JNA, dusky groupers were seen in greater numbers while it was not the case in the surrounding, non-prohibited areas. All respondents agreed that the average catch size of dusky grouper has declined since the late 1990s. The greatest decline in average grouper catch size, over the past decade, was reported by our respondents in the southern Adriatic. In the central Adriatic, from Vis to the Kornati Islands, a smaller decline was also noted.

In terms of behaviour, the majority of respondents noted a shift of large dusky groupers to deeper waters compared to previous periods. Because spearfishing is much more intense in shallow waters, it is likely that fish found refuge in deeper waters due to intense fishing in shallower areas [18]. A change in behaviour and the arrival of larger groupers in shallow water during winter months when there are fewer spearfishermen was also noted by our respondents.

3.2. Juveniles and subadults of Dusky grouper

In Mediterranean waters, Dusky grouper reaches 50% sexual maturity as a female at 43.8 cm standard length (51 cm total length) in the Sicilian Channel [19] and at 57 cm of total length in Algerian waters [22]. We used an average value of these two lengths (50 cm) for sexually mature individuals, corresponding to about 2 kg of weight [1]. Since our respondents were unable to accurately measure the length of individual fish, we took a weight of less than 2 kg as a proxy to consider them juvenile or subadult individuals. Data on the presence of juvenile dusky groupers in the Adriatic Sea is poorly documented. The only mention we found was a comment by French authors where they mention the reported presence of small dusky groupers (< 25 cm LT), but with little information to describe its status in mentioned areas. [15]

Respondents mostly agreed that juvenile and sub-adult dusky groupers started to appear in Croatian waters in the early 1990s. The first dusky grouper weighing less than 2 kg reported by one respondent was caught near Dubrovnik in the late 1980s. Respondents originating from Croatia, who also regularly fished in Montenegrin waters during the times of Yugoslavia, do not remember seeing young dusky groupers. In the spearfishing society at that time, the opinion was that there were no small groupers in the eastern Adriatic. This phenomenon was known primarily to our respondents who had participated in spearfishing competitions in other parts of the Mediterranean where juvenile dusky groupers were present. However, the absence of any evidence of juvenile dusky groupers on the Croatian coast does not allow us to conclude with certainty that there were no juveniles at all. In fact, juveniles may have been present but not seen or recorded. A newspaper article [21] mentions that small groupers were found in southern Croatian

waters, but no size unit or species was given. Many articles from that period mention only large dusky groupers (20+ kg) caught in relatively shallow waters.

One respondent recalled catching a small specimen (approx. 20 cm) as a child on the island of Lastovo (south Adriatic) around the year 1960, and the father of a well-known spearfisherman remembered catching a small dusky grouper near Rovinj (north Adriatic) in the early 1960s. The possible appearance of younger groupers from the mid-1970s was reported near the town of Korčula [22], where juvenile (15 cm) groupers were observed below a peer in shallow water but was erroneously referred to as *P. americanus*. The mentioned article was written to describe the occurrence of *P. americanus* in the south Adriatic, but from the photos of large individuals in the article and the description of the ecology of the mentioned groupers, it is obvious that the author misidentified dusky grouper.

Also, the occurrence of juvenile dusky groupers has not been recorded in the Ligurian Sea north of 41°5 N latitude during the same period [23]. If we consider this latitude, which passes through Albania in the southern Adriatic, as a proxy for similar hydrological conditions (i.e., temperature), we can compare situations in the two seas. The youngest groupers (TL 10 cm) in the Ligurian Sea were observed in the south from 1989-1990, then in the north of Corsica (1990-1992), on the coast of Var (1992-1993) and in the Côte Bleue Marine Park (1999) [24]. Similar south-north migration in the Adriatic in the 1990s was noted in our study.

The emergence of juveniles in the Adriatic Sea could be explained by similar factors as noted by French authors [24]. Recruitment in the southern Adriatic or Ionian Sea may have resulted in juvenile groupers moving northward with the Adriatic current, while the more appropriate temperature created a more favourable environment for their habitat. Warming seas affected the breeding of dusky groupers since temperature positively influences larval development [25]. It was also suggested by several authors [15, 26] that reproduction happens only when the ratio of females to males is adequate in a given area. Without clear data for the Adriatic, this hypothesis cannot be tested.

According to some of our respondents, the next major increase in the number of younger individuals was noticeable in the year 2012 and continues to this day; and respondents indicated that the number of small dusky groupers is steadily increasing, especially in the central Dalmatian and north Dalmatian islands (middle Adriatic).

In 2017, younger dusky groupers began to appear in greater numbers in the northern Adriatic (Fig 2). Since this event was recent, respondents were able to provide more precise data. As of 2017, the size of these individuals was less than 0.5 kg. In the period after 2020, our respondents reported sizes from 0.8 to 3 kg. All of our respondents reported seeing small specimens only in shallow water to a depth of 15 meters. We have no reports of younger specimens from deeper waters.

3.3. White grouper - *Epinephelus aeneus*

The first records of this species in the Adriatic were from February and September 1999, when two specimens were caught near Dubrovnik in the southern Adriatic [27]. However, it was mentioned earlier in the literature [10] when an author observed a 2 kg specimen caught using a longline near the

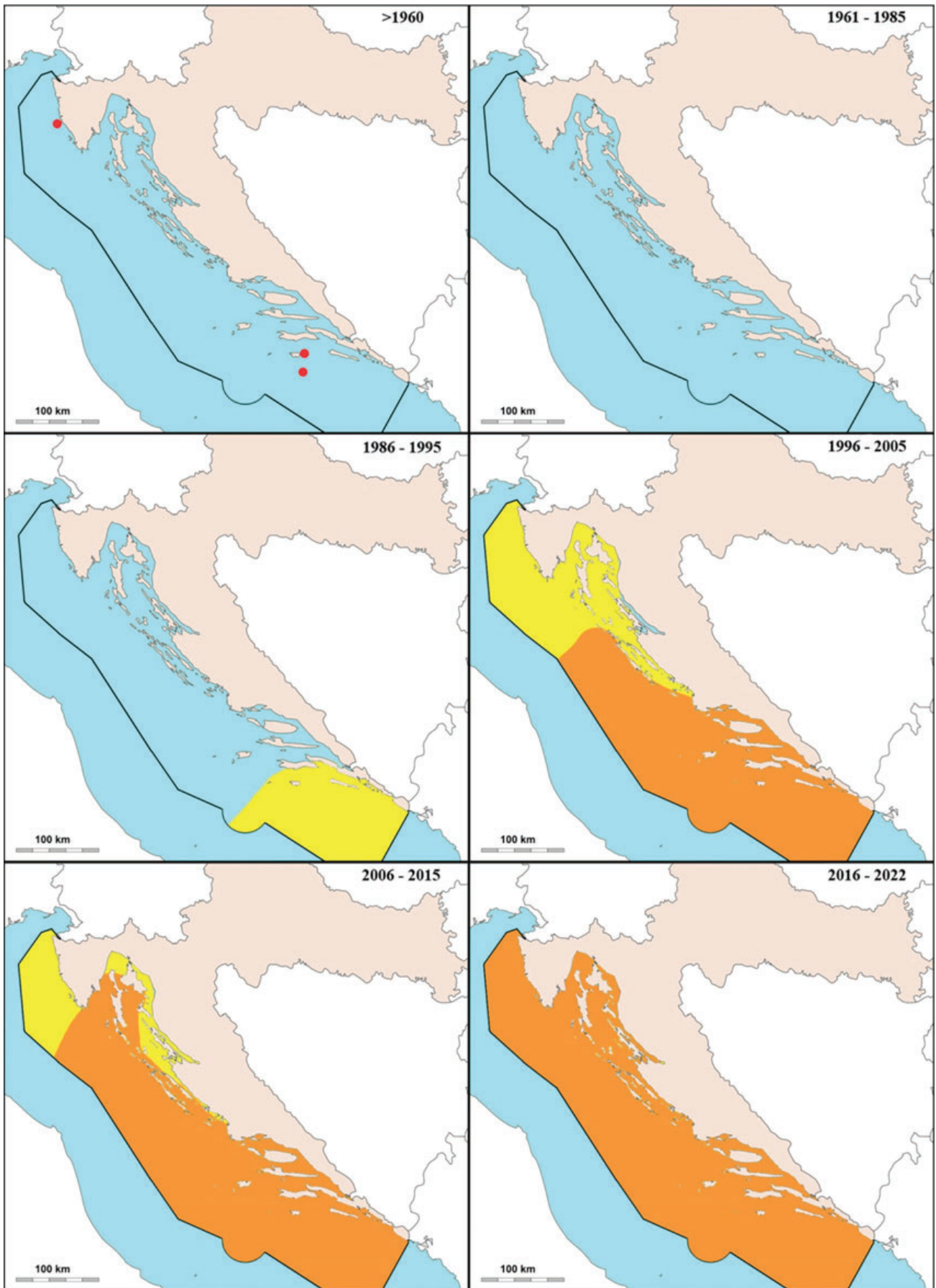


Figure 2 Assumed distribution of dusky grouper *Epinephelus marginatus* juveniles and subadults on the basis of a perception of recreational fishermen for different periods. Red dots represent single records, yellow represents areas where the species was regarded as uncommon, orange is where it was regarded as common.

Kornati archipelago in the central Adriatic. Documented occurrences of this species in the Adriatic are relatively scarce. Besides the first record, only four other confirmed records have been reported [28, 29, 30, 31], the latter being the northernmost record of this species in the Adriatic, caught near Trieste (Italy). Due to the low number of published records, the species was considered very rare in the Adriatic in the mentioned literature. Our study shows that white grouper is indeed a relatively common species, especially in some areas of the southern and central Adriatic.

According to our respondents, white groupers appeared in two different places at the same time, at Koločepski channel near Dubrovnik (south Adriatic), where the catches were reported by many spearfishers in 2002, and the other at Mežanj island near Dugi Otok island (middle Adriatic), where specimens were also caught by several spearfishermen in the same year, while one spearfisherman reported a catch in 1999. In both

areas, white groupers became very common and abundant from then on. Subsequently, they spread to the channels of the middle Adriatic. The first specimen in the northern Adriatic was caught in 2012 on the island of Krk and in 2017 in Istria (Fig 3). A similar northward expansion of white groupers was already reported in Italy and France [32].

The most remarkable catch was made in 2011 near the Mežanj island (middle Adriatic) by a spearfisherman (Fig 6), when a specimen was caught that reportedly weighed 25 kg, which is the maximum weight reported for this species [33]. This is a protogynous hermaphroditic species that reportedly does not become sexually mature as a female until 5 to 7 years of age (total length 50-60 cm, weight about 4 kg) [34], and sex change occurs at 10 to 13 years of age (total length 80-110 cm, weight 6-15 kg) [35]. This indicates that the mentioned specimen was much older than would be expected considering the time period since the first groupers were reported in the Adriatic.

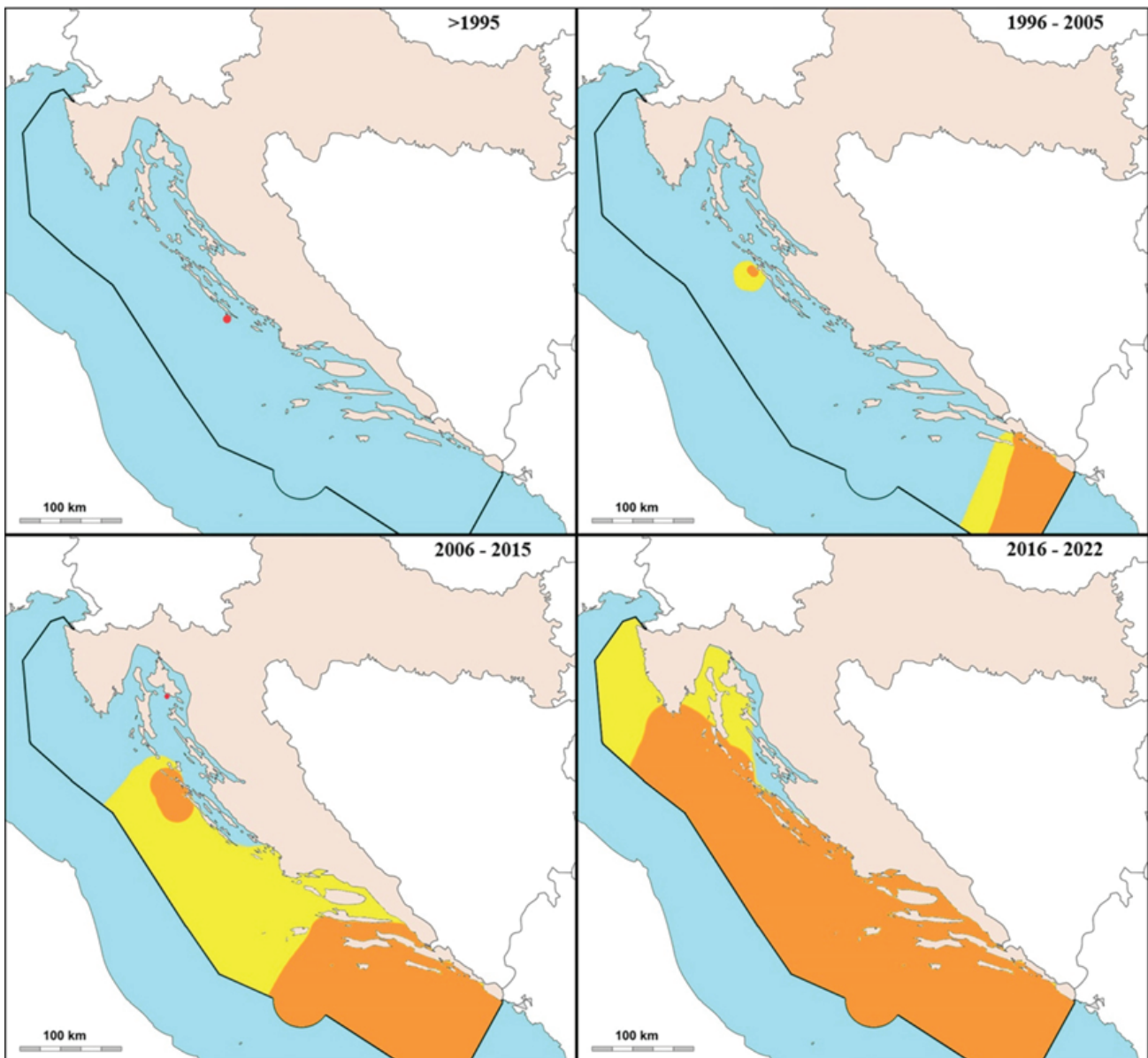


Figure 3 Assumed distribution of white grouper *Epinephelus aeneus* on the basis of a perception of recreational fishermen for different periods. Red dots represent single records, yellow represents areas where the species was regarded as uncommon, and orange is where it was regarded as common.

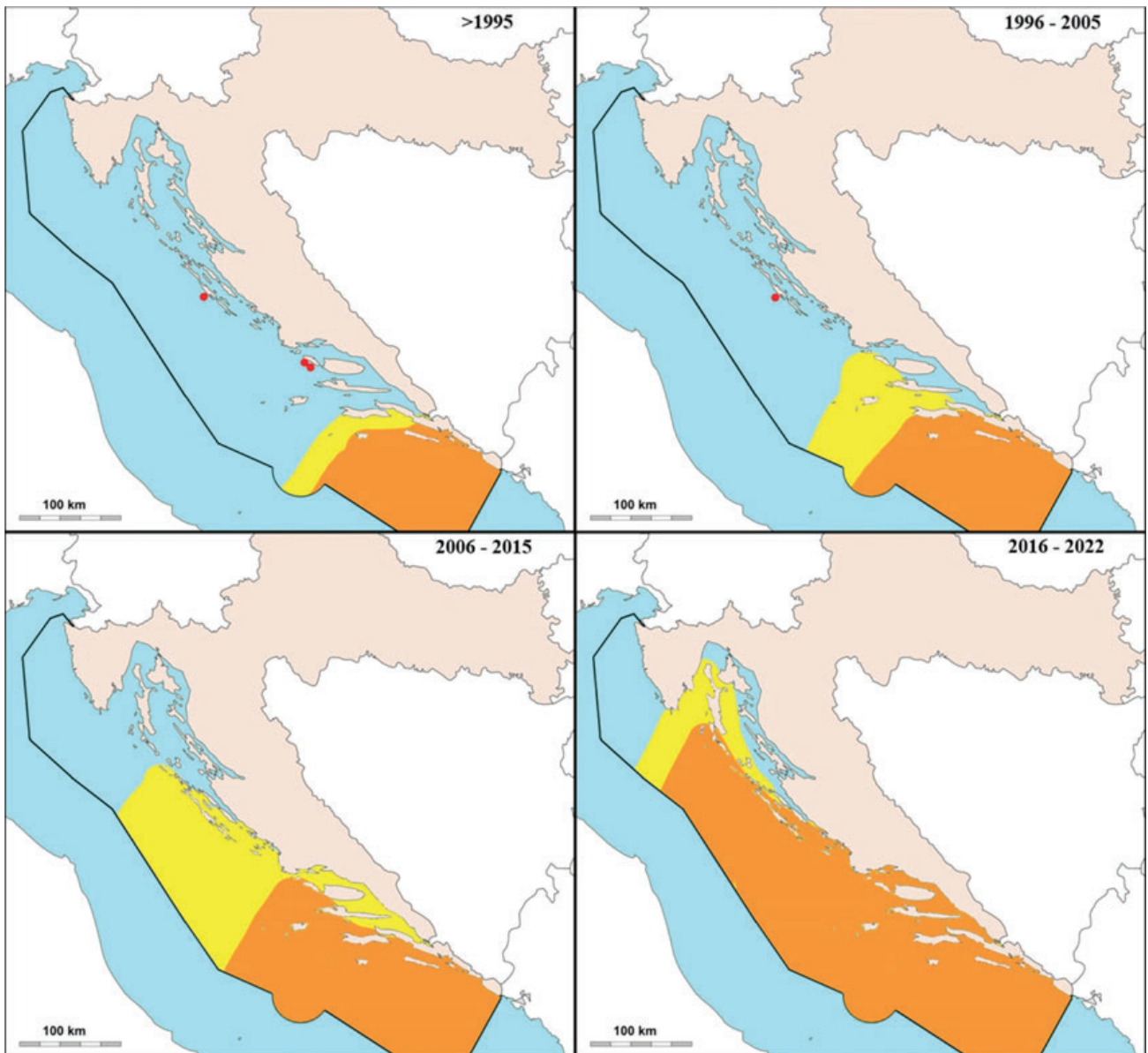


Figure 4 Assumed distribution of goldblotch grouper *Epinephelus costae* on the basis of a perception of recreational fishermen for different periods. Red dots represent single records, yellow represents areas where the species was regarded as uncommon, and orange is where it was regarded as common.

3.4. Goldblotch grouper - *Epinephelus costae*

This is a demersal species that occurs in coastal waters at depths of 1-200 m, more commonly at depths between 10 and 80 m, on sandy, muddy and rocky bottoms [1, 33]. The maximum length of this species is reported to be 140 cm [1]. Goldblotch grouper has always been considered a species inhabiting the southern Adriatic [36] but is also described as a relatively rare species in the southern Adriatic [6]. In the more recent literature [2], its distribution is restricted to the southern part of the Adriatic. In this study, its current range is extended to almost the entire Adriatic, and in most areas goldblotch grouper can be considered a relatively common species.

Our senior respondents agreed that it was a rare species, occurring exclusively south of the island of Korčula (south Adriatic). The mention of goldblotch grouper in the central Adriatic dates back to the year 1884, when a specimen was reported from an area near the town of Split (middle Adriatic) [37]. Two older respondents reported that it was caught on

Šolta island (middle Adriatic) in the mid-1970s, while it is possible that another respondent caught it on island Šolta and confused it with *M. rubra*. These reports are only from a short period in the mid-1970s, while no occurrence of this species has been reported from other localities in the middle Adriatic. The next report of this species from the central Adriatic dates from the 1990s by a spearfisherman who observed it on the southern side of the island of Dugi Otok (middle Adriatic).

The shift of this species to the north and reports of denser populations can be traced from our respondents' reports after the year 2000, when spearfishermen reported its presence in almost the entire middle Adriatic, while it became more common in the southern Adriatic. In 2017, all respondents from the northern Adriatic reported a mass movement of juvenile *E. costae* into the northern Adriatic area of the Lošinj archipelago and part of the Istrian peninsula (Fig 4). Unlike *E. marginatus* and *E. aeneus*, which were first noticed in newly colonized areas as mature fishes, *E. costae* were initially observed in newly

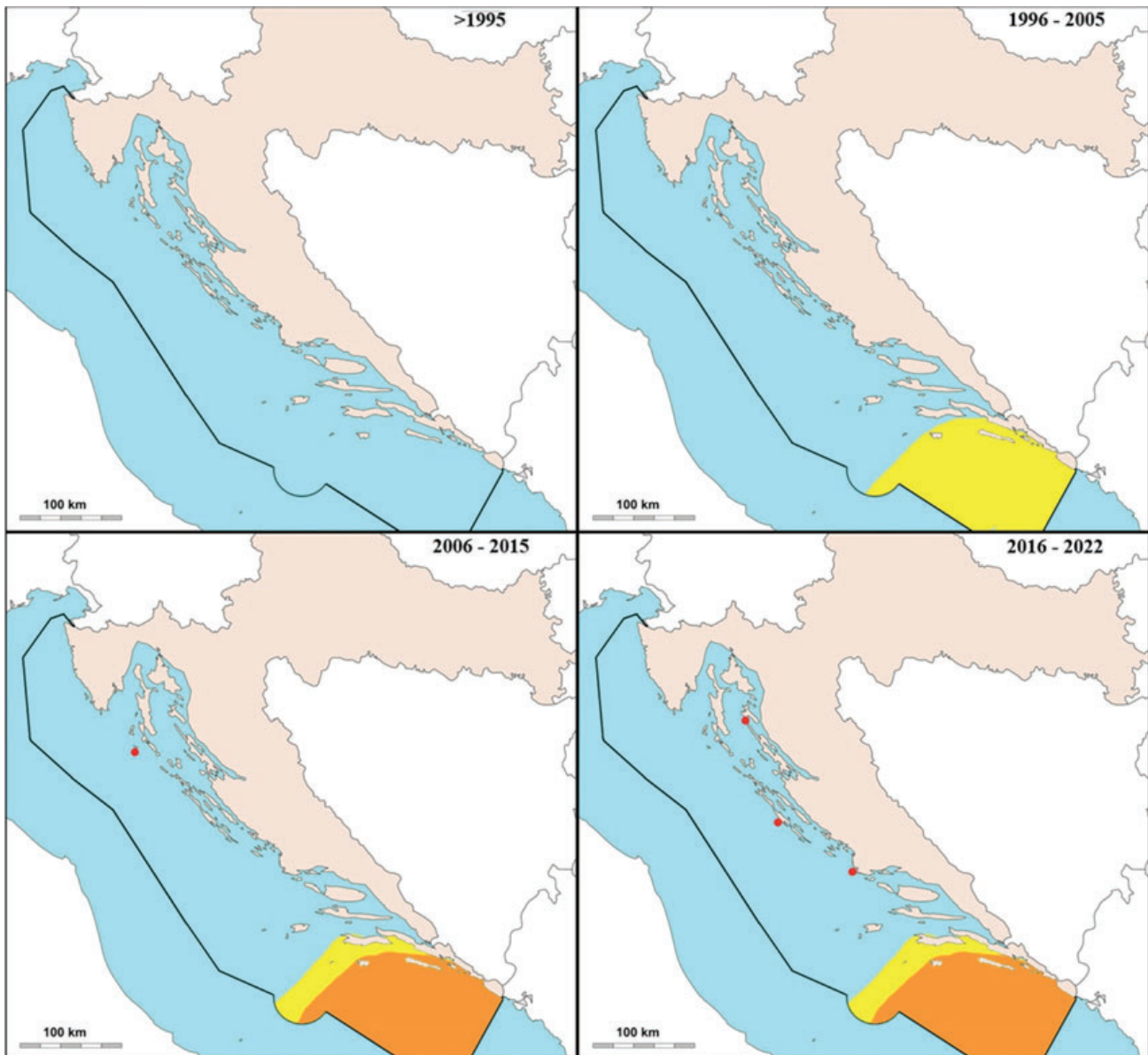


Figure 5 Assumed distribution of mottled grouper *Mycteroperca rubra* on the basis of a perception of recreational fishermen for different periods. Red dots represent single records, yellow represents areas where the species was regarded as uncommon, and orange is where it was regarded as common.

colonized areas as small fishes (<1 kg), which was particularly noticeable in recent post-2017 movements to the waters of the northern Adriatic, where the increase in the number and size of individuals over time was evident on the basis of respondents reports.

3.5. The mottled grouper - *Mycteroperca rubra*

This species can easily be confused with goldblotch grouper, so reports of sightings or catches without photographic evidence should be taken with greater caution. For instance, a respondent claimed that mottled groupers occurred on the island of Šolta (middle Adriatic) in the mid-1970s, in the area where goldblotch groupers have been identified in the past [37], as well as other respondents for the same location and time period. A similar suspicious report by a respondent dates to the late 1980s from a nearby area.

The only confirmed record of mottled grouper in the Adriatic dates from September 2000 [38]. In addition, four other

unconfirmed sightings were reported in the same publication. Four of our respondents reported catches and multiple sightings in the second half of the 1990s at the Elafiti archipelago (south Adriatic), including a spearfishing competitor who already had the opportunity to catch mottled grouper in the western Mediterranean. Since this is a location identical to the first confirmed record, but only a few years before, the statements of our respondents suggest that mottled groupers may have settled in this area earlier.

Prior to 2010, only a few records of this species were reported, all of which were from southern Croatian waters. The only exception was the testimony of two spearfishermen who claimed to have sighted a single specimen on the island of Susak in 2006 in the northern Adriatic, but no photographic evidence was provided. After 2011, the species became more common in the south and some more records appeared in other locations (Fig 5). The northernmost confirmed record is from the island of Rab on March 8, 2013 (Fig 7).



Figure 6 White grouper *Epinephelus aeneus*, caught in 2011 near Mežanj island. Fishermen reported the weight to be 25 kg, which is the maximum size of this species.



Figure 7 The northernmost confirmed record of mottled grouper *Mycteroperca rubra* from the island of Rab, March 8th, 2013.

4. CONCLUSION

The Adriatic Sea is the coldest part of the Mediterranean with winter temperatures below 10 °C in its northern part [39]. Sea surface temperature (SST) data show a cooling period (pre-1979) and a warming period (1979-2015), with the latter resulting in an SST increase exceeding 1 °C, and the warming has particularly intensified since 2008 with a trend of up to 1.56 °C per decade [40]. The temperature increase in the Adriatic created the conditions for the phenomenon of meridionalization. Native thermophilic fish species spread from southern to northern parts of the Mediterranean and also the Adriatic Sea mainly as a consequence of rising sea temperature [41]. The northward advance of thermophilic species was the first and most cited evidence of the link between climate change and Mediterranean biodiversity distribution patterns [42].

The grouper species of the subfamily Epinephelinae examined in this study represent a typical example of native thermophilic fishes of the Mediterranean. To gain insight into the temporal and spatial changes of grouper species and motivated by the lack of historical data, we conducted a survey of local ecological knowledge of recreational fishers in the eastern Adriatic which served as a proper method to fill the gap. All grouper species have shifted their distributions northwards in the Adriatic Sea during the last three decades, which corresponds to the same pattern described in other Mediterranean regions [24, 32, 42]. The only exception is *E. caninus*, whose northward spreading is limited by the shallow northern Adriatic, due to its habitat preferences. Our study indicates that juveniles and sub-adult individuals of *E. marginatus* were not observed in the eastern Adriatic Sea from at least the early 1960s until the late 1980s, while at the same

time, the adult specimens could be found in the southern and middle Adriatic. The northward migration of dusky grouper was first observed in the late 1980s in adult specimens (>2 kg), while juvenile and subadult specimens experienced expansion later. The same phenomenon was observed for *E. aeneus*, first recorded in the Adriatic in the early 2000s and already caught by recreational fishermen in two different locations in the southern and middle Adriatic. In contrast, juvenile and sub adult specimens of *E. costae* first appeared as juveniles (<1 kg), particularly after 2017 in the northern Adriatic waters around the Lošinj archipelago. This species has always been present in the Adriatic, especially in its southern part. The expansion to the north occurred after the early 2000s. Today, recreational fishermen consider it a common species, particularly in the southern and middle Adriatic. *M. rubra* probably colonized the southern Adriatic in the late 1990s, when it was first recorded [38]. After 2010, the fish became more common in the southern Adriatic waters while in the other parts of Croatia, it is still unknown to most recreational fishers, although there are records from the middle and northern Adriatic.

The expansion of groupers in a northward direction in the Adriatic Sea has many implications. The expansion of thermophilic fish species can have an impact on native fish communities through increased competition, but also through predation which may alter the structure and composition of food networks and fish communities. Understanding the patterns of fish distribution and migration in response to climate change is crucial for the effective management of fisheries and the conservation of biodiversity in the Adriatic Sea. Further research is needed to fully understand the implications of these changes and to develop strategies for potential adaptation to novel ecological conditions.

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REFERENCES

- [1] Froese, R. and D. Pauly. Editors. (2022). FishBase. World Wide Web electronic publication. www.fishbase.org, (08/2022)
- [2] Dulčić, J. & Kovačić, M. (2020). *Ihtiofauna Jadranskog Mora*. Golden Marketing-Tehnička Knjiga, Zagreb and Institute of Oceanography and Fisheries Split, Split, Croatia. (In Croatian)
- [3] Parenti, P. & Bressi, N. (2001). First record of the orange spotted grouper, *Epinephelus coioides* (Perciformes: Serranidae) in the northern Adriatic Sea. *Cybio*, 25(3), 281-284. <https://doi.org/10.26028/cybio/2001-253-011>
- [4] Manooch, C.S. III, (1987). Age and growth of snappers and groupers. p. 329-373. In J.J. Polovina and S. Ralston (eds.) *Tropical snappers and groupers: biology and fisheries management*. Ocean Resources Marine Policy Services. Westview Press, Inc., Boulder and London.
- [5] Begossi, A., Salyvonchik, S., Glamuzina, B., Pacheco de Souza, S., Lopes, P. F. M., Priolli, R. H. G., Osmanir do Prado, D., Ramires, M., Clauzet, M., Zapelini, C., Schneider, D. T., Silva, L. T. & Silvano, A. M. (2019). Fishers and groupers (*Epinephelus marginatus* and *E. morio*) in the coast of Brazil: integrating information for conservation. *Journal of Ethnobiology and Ethnomedicine*, 15, 53. <https://doi.org/10.1186/s13002-019-0331-2>
- [6] Glamuzina, B. & Skaramuca, B. (1999). A review: Adriatic groupers - Status of natural populations and breeding perspectives. *Acta Adriatica*, 40(3), 79-90.
- [7] Narodne novine br. 46/96. *Naredba o zaštiti riba i drugih morskih organizama* (In Croatian). Retrieved from https://narodne-novine.nn.hr/clanci/sluzbeni/1996_06_46_888.html
- [8] Lloret, J., Zaragoza, N., Caballero, D., Font, T., Casadevall, M. & Riera, V. (2008). Spearfishing pressure on fish communities in rocky coastal habitats in a Mediterranean marine protected area. *Fisheries Research*, 94(1), 84–91. <https://doi.org/10.1016/j.fishres.2008.07.002>
- [9] Jardas, I. (1996). *Adriatic Ichthyofauna* 1st edition. Školska Knjiga, Zagreb, Croatia. (In Croatian).
- [10] Milišić, N. (1994). *All the Fishes of the Adriatic*. NIVA, Split, Croatia. (In Croatian)
- [11] Bettoso, N., Faresi, L., Felluga, A. & Lipej, L. (2020). On the occurrence of the wreckfish *Polyprion americanus* in the Gulf of Trieste (northern Adriatic Sea). *Acta Adriatica*, 61(1), 107-112. <https://doi.org/10.32582/aa.61.1.9>
- [12] Dragičević, B., Matić-Skoko, S. & Dulčić, J. (2017). Fish and Fisheries of The Eastern Adriatic Sea in The Light of Climate Change. In: *Trends in Fisheries and Aquatic Animal Health, Berillis, Panagiotis (Ed.)*. Sharjah UAE, Bentham e-books. <https://doi.org/10.2174/9781681085807117010004>
- [13] Begossi, A. & Silvano, R. A. M. (2008). Ecology and ethnoecology of dusky grouper [garoupa, *Epinephelus marginatus* (Lowe, 1834)] along the coast of Brazil. *Journal of Ethnobiology and Ethnomedicine*, 4, 20. <https://doi.org/10.1186/1746-4269-4-20>
- [13] Harmelin, J. G. & Harmelin-Vivien, M. (1999). A review on habitat, diet and growth of the dusky grouper *Epinephelus marginatus* (Lowe, 1834). *Marine Life*, 9(2), 11–20.
- [14] La Mesa, G., Louisy, P. & M. Vacchi. (2002). Assessment of microhabitat preferences in juvenile dusky grouper (*Epinephelus marginatus*) by visual sampling. *Marine Biology*, 140, 175-185. <https://doi.org/10.1007/s002270100682>
- [15] Bodilis, P., Ganteaume, A. & Francour, P. (2003). Presence of 1 year-old dusky groupers along the French Mediterranean coast. *Journal of Fish Biology*, 62, 242-246. <https://doi.org/10.1046/j.1095-8649.2003.00028.x>
- [16] Raffaele Seiello (2019, August 13) *Spearfishing into the deep 64, 2m*. Retrieved from: https://www.youtube.com/watch?v=X0q_Wk6-ICU
- [17] Šuljić, B. & Prokić V. (2018). *Povijest podvodnog ribolova na Jadranu*. Hrvatski savez za športski ribolov na moru. Rijeka, Croatia. (In Croatian).
- [18] Lindfield, S. J., McIlwain, J. L. & Harvey E. S. (2014). Depth Refuge and the Impacts of SCUBA Spearfishing on Coral Reef Fishes. *PLoS ONE*, 9(3), e92628. <https://doi.org/10.1371/journal.pone.0092628>
- [19] Marino, G., Azzurro, E., Massari, A., Foino, M. G. & Mandich, A. (2001). Reproduction in the dusky grouper from the southern Mediterranean. *Journal of Fish Biology*, 58(4), 909–927. <https://doi.org/10.1111/j.1095-8649.2001.tb00544.x>
- [20] Kara, M. H. & Derbal, F. (1999). Données biologiques sur le mérou *Epinephelus marginatus* (Lowe, 1834) des côtes Algériennes. *Marine Life*, 9(2), 21-27.
- [21] Anonymous (1959. July 1) *Novi stanovnici splitskog akvarija*. Slobodna Dalmacija, p. 6. (In Croatian)
- [22] Onofri, I. (1977). Kirnja glavulja (*Polyprion americanus*, Schne. [sic]) iz kanala uz otok Korčulu. *Ribarstvo*, XXIX (2), 66-67. (In Croatian)
- [23] Chauvet, C. & Francour, P. (1990). Les mérous du parc national de Port-Cros: aspects socio-démographiques. *Bulletin de la Société zoologique de France*, 114, 5-13.
- [24] Bodilis, P., Ganteaume A. & Francour P. (2003). Recruitment of the dusky grouper (*Epinephelus marginatus*) in the north-western Mediterranean Sea. *Cybio*, 27(2), 123-129.
- [25] Dantart, L., Rovira, P., Hereu, B. & Duda, A. (1999). Early development of the dusky grouper (*Epinephelus marginatus*) from natural spawns. In *1st Symposium International sur les Mérous de Méditerranée*, 37–43. Toulon: Memoirs de l'Institut Oceanographique Paul Ricard.
- [26] Zabala, M., Louisy P., Garcia-Rubies A. & Gracia V. (1997). Sociobehavioural context of reproduction in the Mediterranean dusky grouper *Epinephelus marginatus* (Lowe, 1834) (Pisces, Serranidae) in the Medes Islands Marine Reserve (NW Mediterranean, Spain). *Scientia Marina*, 61(1), 79–98
- [27] Glamuzina, B., Tutman, P., Geffen, J.A., Kožul, V. & Skaramuca, B. (2000). First record of white grouper, *Epinephelus aeneus* (Serranidae) in the south eastern Adriatic. *Cybio*, 24(3), 306-308. <https://doi.org/10.26028/cybio/2000-243-010>
- [28] Bo, M., Al Mabruk S. A., Balistreri, P., Bariche, M., Batjakas, I. E., Betti, F., Bilan, M., Canese, S., Cattaneo-Vietti, R., Corsini-Foka, M., Crocetta, F., Deidun, A., Dulčić, J., Grinyó, J., Kampouris, T. E., Ketsilis-Rinis, V., Kousteni, V., Koutsidi, M., Lubinevsky, H., Mavruk, S., Mytilineou, C., Petani, A., Puig, P., Salomidi, M., Sbragaglia, V., Smith, C. J., Stern, N., Toma, M., Tsiamis, K., Zava, B., & Gerovasileiou, V. (2020). New records of rare species in the Mediterranean Sea (October 2020). *Mediterranean Marine Science*, 21(3), 608–630. <https://doi.org/10.12681/mms.23674>
- [29] Dulčić, J., Tutman, P. & Čaleta, M., (2006). Northernmost occurrence of the white grouper, *Epinephelus aeneus* (Perciformes: Serranidae), in the Mediterranean area. *Acta Ichthyologica et Piscatoria*, 36(1), 73-75. <https://doi.org/10.3750/AIP2006.36.1.10>
- [30] Đodo, Z., Antolović, N. & Dulčić, J. (2016). New record of white grouper *Epinephelus aeneus* (Osteichthyes: Serranidae) in Croatian Adriatic waters. *Annales: Series Historia Naturalis*, 26(1), 37-40.
- [31] Glamuzina, B., Bartulović, V., Glamuzina, L. & Dobroslavić, T. (2017). Records of new fish species in the River Neretva Estuary: potential threat to coastal Adriatic nursery. *Naše more*, 64(3), 86-89. <https://doi.org/10.17818/NM/2017/3.2>
- [32] Sbragaglia, V., Coco, S., Correia, R., Coll, M. & Arlinghaus, R. (2021). Analyzing publicly available videos about recreational fishing reveals key ecological and social insights: A case study about groupers in the Mediterranean Sea. *Science of The Total Environment*, 765, 142672. <https://doi.org/10.1016/j.scitotenv.2020.142672>
- [33] Heemstra, P. C. & Randall, J. E. (1993). *FAO Species Catalogue. Vol. 16. Groupers of the world (family Serranidae, subfamily Epinephelinae)*. An annotated and illustrated catalogue of the grouper, rockcod, hind, coral grouper and lyretail species known to date. Rome: FAO. *FAO Fisheries Synopsis*, 125(16), 382.
- [34] Bouain, A. & Siau, Y. (1983). Observations on the female reproductive cycle and fecundity of three species of groupers (*Epinephelus*) from the southeast Tunisian seashores. *Marine Biology*, 73 (2), 211-220. <https://doi.org/10.1007/BF00406890>
- [35] Bruslé, J. (1985). Exposé synoptique des données biologiques sur les mérous *Epinephelus aeneus* (Geoffroy Saint Hilaire, 1809) et *Epinephelus guaza* (Linnaeus, 1758) de l'Océan Atlantique et de la Méditerranée. Food and Agriculture Organization (FAO), *FAO Synopsis sur les pêches*, 129, 64.
- [36] Kosić, B. (1898). Dodatak novoj građi za dubrovačku nomenklaturu i faunu riba. *Glasnik Hrvatskoga Naravoslovnoga Društva*, Zagreb, Croatia. Godina X broj 1-5, 77–84.
- [37] Kolombatović, G. (1882 – 1884). Notizie sui pesci del circondario marittimo di Spalato, Teleostei Acanthopterygii. *Glasnik Hrvatskoga Naravoslovnoga Društva*, Zagreb, Croatia. Godina VI, pp. 172–204.
- [38] Glamuzina, B., Tutman, P., Kožul, V., Glavić, N. & Skaramuca, B. (2002). The first recorded occurrence of mottled grouper, *Mycteroperca rubra* (Serranidae), in the southeastern Adriatic Sea. *Cybio*, 26(2), 156-158.
- [39] Malačić, V., Celio, M., Cermelj, B., Bussani, A. & Comici, C. (2006). Interannual evolution of seasonal thermohaline properties in the Gulf of Trieste (northern Adriatic) 1991–2003. *Journal of Geophysical Research*, 111, 1–16. <https://doi.org/10.1029/2005JC003267>
- [40] Grbec, B., Matić, F., Beg Paklar, G., Morović, M., Popović, R. & Viličić, I. (2018). Long-term trends, variability and extremes of in situ sea surface temperature measured along the eastern Adriatic coast and its relationship to hemispheric processes. *Pure and applied geophysics*, 175, 4031-4046. <https://doi.org/10.1007/s00024-018-1793-1>
- [41] Lipej, L., Kovačić, M. & Dulčić, J. (2022). An Analysis of Adriatic Ichthyofauna—Ecology, Zoogeography, and Conservation Status. *Fishes*, 7(2), 1-58. <https://doi.org/10.3390/fishes7020058>
- [42] Azzurro, E. (2008) The advance of thermophilic fishes in the Mediterranean Sea: Overview and methodological questions. In: Briand, F, editor. *Climate warming and related changes in Mediterranean marine biota*. Monaco: CIEM Workshop Monographs. pp. 39–45.