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Research Article

Perceptions of Climate Change Impacts on Small-Scale Fisheries in Gabes Governorate (Tunisia, Central Mediterranean): Evidence from Structured Surveys

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Abstract: Small-scale fisheries in the Mediterranean face significant risks from climate change, but the views of local fishers are not always well represented in scientific research. This study examines how coastal fishers in Gabes Governorate (Tunisia), perceive and experience climate change. This region is located in the center of the Gulf of Gabes, one of the Mediterranean's most important and threatened coastal areas.

The research involved 55 structured surveys conducted from May to September 2024 at three landing sites: Gabes, Ghannouch, and Zarat.

All respondents were aware of climate-related environmental issues, and 96% had personally seen changes in weather or sea conditions. The rise in sea surface temperature was the most commonly noted factor affecting ecosystems, with 75% of fishers reporting it (mean perceived intensity = 0.60 on a 0-1 scale), followed by sea level rise at 44% and ocean acidification (bleaching of Posidonia seagrass beds and the weakening of shellfish) at 29%. In addition, 93% of fishers reported declines in fish stocks and changes in fish behavior. Furthermore, 82% noted the deterioration of seagrass and Posidonia meadows, which are crucial nursery habitats. One serious threat to small-scale fisheries is biological invasions caused by warming seas. Fishers frequently mentioned the non-native portunid crabs *Portunus segnis* and *Callinectes sapidus* as well as the Mediterranean native jellyfish blooms (*Pelagia noctiluca*), as causing damage, competition, and loss of revenue.

Economic losses from lower catches affected 80% of fishers, while 93% reported damage from extreme weather events. Adaptation efforts included spontaneously using crab traps to target invasive species and expanding fishing areas. These findings offer important evidence for climate-informed management of fisheries in the Gulf of Gabes and highlight the importance of including fishers' ecological knowledge in assessing and managing fish stocks.

Keywords: small-scale fisheries; climate change; local ecological knowledge; biological invasions; socioeconomic aspects; Gabes Governorate; Gulf of Gabes; Central Mediterranean.

1. Introduction

Climate change is reshaping the physical and biological conditions of the world's oceans. Rising Sea Surface Temperatures (SST), ocean acidification, changing rainfall patterns, and more frequent extreme weather events are altering marine ecosystems in ways that threaten the livelihoods of fishing communities worldwide (Hidalgo et al. 2022, IPCC, 2023; Cheung et al., 2010).

The Mediterranean Sea is warming at a rate of about 20% faster than the global ocean average (Lionello & Scarascia, 2018). It is particularly vulnerable to these changes, leading to significant effects on fish distribution, recruitment success, and coastal habitat integrity. One of the least visible but most impactful effects is the increase in biological invasions. Warmer seas lower the thermal barriers that once limited the spread of non-indigenous species (NIS). This change allows thermophilic and exotic species to quickly colonize new areas (Rahel & Olden, 2008; Bax et al., 2003).

Small-Scale Fisheries (SSF) operate in nearshore waters. They are essential for coastal livelihoods across the Mediterranean. These fisheries account for a large number of fishing vessels in the region and support thousands of jobs. They also provide a low-carbon source of animal protein compared to industrial fisheries or land-based livestock (Coll et al., 2008; FAO, 2020).

Unlike industrial fleets that can track fish movements over large areas, small-scale fishers are mostly limited to the coastal waters close to their home ports. This makes them highly vulnerable to local environmental changes.

These changes include the arrival and spread of invasive species that compete with target species, damage fishing gear, or occupy important habitats (Allison et al., 2009; Katsanevakis et al., 2014).

The Gabes Governorate (Tunisia, Central Mediterranean) is unique in that it encompasses both an oasis and a seaport. Located in the central part of the Gulf of Gabes, it is influenced by both coastal and desert environments, which have, over time, had a considerable impact on coastal ecosystems, marine resources, and, in particular, coastal fisheries (Béjaoui et al., 2004).

Gabes is facing a severe environmental crisis due to industrial pollution from the local phosphate chemical complex. For decades, the direct discharge of millions of tons of toxic phosphogypsum into the Sea has severely degraded marine biodiversity and damaged the unique coastal oasis ecosystem.

In addition, the continuous emission of hazardous chemical gases has significantly deteriorated air quality, contributing to an alarming increase in respiratory diseases and cancer among local residents (Saied & Lahmar, 2021).

In data-poor regions or areas experiencing rapid ecological shifts, Local Ecological Knowledge (LEK) has emerged as a crucial scientific tool to complement traditional monitoring methods. LEK provides high-resolution, long-term historical insights into ecosystem changes directly from the primary observers of the marine environment, the fishers themselves (Johannes et al., 2000; Azzurro et al., 2019). By capturing real-time observations on the arrival of non-indigenous species, shifts in fish behavior, and modifications in species distribution, LEK bridges critical data gaps where continuous scientific surveys are lacking (Beaudreau & Levin, 2014).

Integrating this empirical knowledge into scientific frameworks not only enhances the accuracy of vulnerability assessments but also fosters community-based management and adaptive conservation strategies.

Despite its regional importance, several aspects of coastal fishing, also known as artisanal fishing, remain insufficiently studied, particularly those related to vulnerability to climate change. Accordingly, this study aims to assess the perception of fishers on certain impacts of climate change on coastal fisheries, the main type of fishing in the Governorate of Gabes.

2. Materials and Methods

2.1. Study area

The Gabes Governorate is located along the eastern coast of Tunisia (figure 1), on the central shore of the Gulf of Gabes (32°30'-35°N, 9°30'-12°E).

The governorate's coastal zone is home to some of the most extensive *Posidonia oceanica* seagrass beds in the eastern Mediterranean. Three main landing sites were selected: the port of Gabes (33°53'N, 10°06'E), Ghannouch (33°57'N, 10°03'E), near the phosphate processing industrial complexes, and Zarat (33°47'N, 10°12'E). Fishing in these areas is primarily carried out by motorized coastal vessels (< 12 m) using trammel nets, longlines, gillnets, and traps.

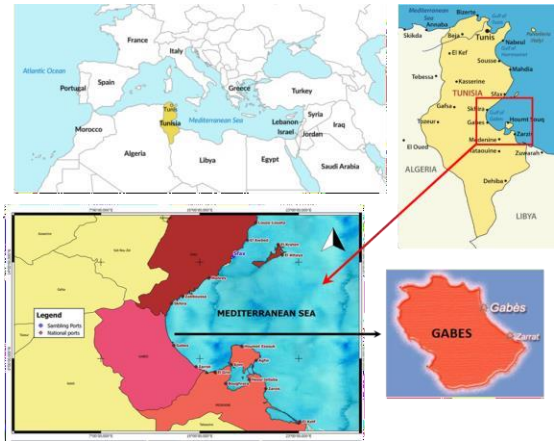


Figure 1. Position of the Governorate of Gabes (Tunisia, southeastern Mediterranean).

2.2. Survey Design and Data Collection

In order to assess the perception of local fishers on the impacts of climate change on coastal fisheries in the Gabes region, by analyzing their perception of current effects on fish stocks, marine biodiversity, and the socioeconomic conditions of fishermen, while identifying adaptation strategies that have been implemented or are needed for the sustainable management of marine resources, we conducted 55 surveys.

A structured survey, comprising five thematic sections, (i) sociodemographic data; (ii) climate change awareness; (iii) fish stocks and fisheries dynamics; (iv) biodiversity, habitats, and non-native species; and (v) socioeconomic impacts and adaptation, was administered in person at three landing sites in the Gabes Governorate, Gabes port (76% of the surveys), Ghannouch (16%) and Zarat port (7%), between May and September 2024.

Participants were not selected through strict random sampling. Instead, sampling was opportunistic: fishermen present at the ports at the time of the interviews were surveyed, with no formal selection procedure applied.

The unequal distribution across sites reflects differences in the number of active registered fishing vessels at each port rather than a deliberate oversampling strategy: Gabes port accommodates by far the largest proportion of the active SSF fleet in the Governorate, followed by Ghannouch and Zarrat.

The questionnaire is provided as Supplementary Material S1 to facilitate replication and methodological transparency. Fishers were interviewed using a convenience-purposive sampling strategy: all active fishers present at the port landing area during the survey period who consented to participate were enrolled.

This approach was chosen to maximize ecological representativeness (experienced, active fishers) and logistical feasibility; it does not constitute random probabilistic sampling. Responses should therefore be interpreted as reflecting the

perceptions of regularly active fishers at these landing sites rather than a statistically random cross-section of the registered fleet.

2.3. Key variables

Binary awareness and observed-change questions; perceived intensity scores (0-1 scale) for SST, sea level rise, ocean acidification and circulation changes; species-level observations of stocks, behavior, size and phenology; NIS impact intensity scored across four categories (revenue loss, predation on catches, habitat exclusion, gear damage); and socioeconomic impact and adaptation inventories.

For key variable that a respondent reported having perceived, respondents were asked to score the perceived intensity of change on a continuous 0-1 scale, where 0 indicates no perceivable change and 1 indicates the maximum conceivable change. Enumerators explained this scale verbally using reference points: a score of 0.25 was described as 'slight and occasional change', 0.50 as 'moderate and recurring change', 0.75 as 'strong and consistent change', and 1.0 as 'complete or catastrophic change'.

These anchors were designed to be interpretable by fishers without formal scientific training**.**

For key non-indigenous species, an interview-based question was used to estimate the average quantities landed per fishing trip, with the aim of assessing perceived changes in their abundance over time.

2.4. Data analysis

Data were coded and cleaned in Microsoft Excel and analyzed in R (v4.3.2). Descriptive statistics, Pearson correlation (experience vs. SST intensity), Fisher's exact test (stock decline by site), and t-tests (experience vs. economic impact) were applied ($\alpha = 0.05$).

Descriptive statistics (frequencies, means ± SD, medians, interquartile ranges) were computed for all socio-demographic and response variables to characterize the sample and summarize the distribution of perceptions across respondents.

3. Results

3.1. Socio-Demographic Profile

A total of 55 complete surveys were collected across Gabes Governorate. Respondents (figure 2) ranged in age from 20 to 65 years (mean 42.2 ± 11.2 years).

Fishing experience, defined as the total number of years during which the respondent has been actively engaged in fishing activities, ranged from 3 to 45 years (mean 21.4 ± 11.9 years).

Roles included boat captains (65%) and crew members (35%). All vessels were motorized coastal boats.

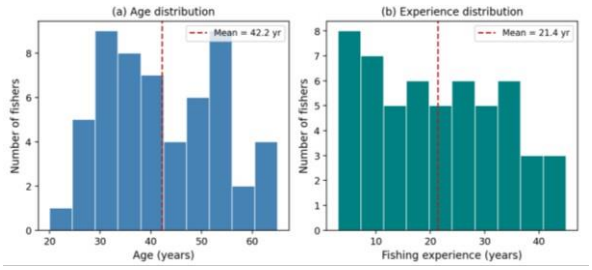


Figure 2. Socio-demographic profile of the 55 small-scale fishers surveyed in Gabes Governorate in 2024: (a) age distribution; (b) fishing experience distribution.

3.2. Climate Change Awareness and Perceived Ecosystem Changes

All 55 respondents to the question on awareness (figure 3(a)) confirmed that they were aware of phenomena related to climate change (100%).

Similarly, 96% of respondents reported having personally observed changes in weather or sea conditions.

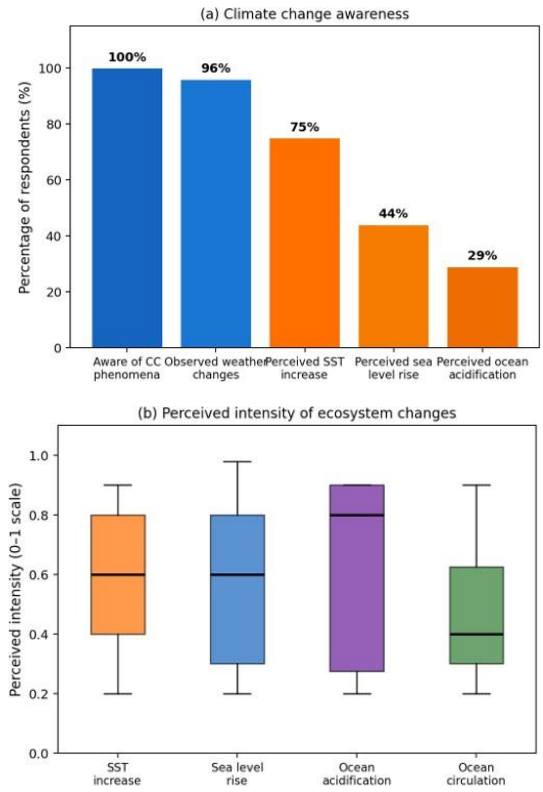


Figure 3. (a) Percentage of fishers reporting awareness of or observation of climate-related changes; (b) Distribution of perceived intensity scores (0-1) for four ecosystem drivers among fishers in Gabes Governorate (2024).

The increase in SST was identified (figure 3(b)) as the most widely perceived factor (75%), with an average perceived intensity of 0.60 ± 0.22. Sea-level rise was perceived by 44% respondents, ocean acidification by 29%, and changes in ocean circulation (observed primarily through changes in the intensity and direction of ocean currents, the unusual drifting of fishing gear, and the shifting of sandbars and the silting up of harbors) by 25%.

A positive but non-significant correlation was observed between fishing experience and intensity scores related to SST (Pearson's r = 0.24, p = 0.09).

3.3. Impacts on Fish Stocks and Fishing Dynamics

51 of the 55 respondents (93%) reported a decline in fish stocks, and this was consistent across all landing sites in the Gabes Governorate (Fisher's exact test, p = 0.87). The species most frequently cited as being in decline included *Octopus vulgaris* (71% of fishermen), *Sepia officinalis* (22%), *Scomber scombrus* (22%), *Sardina pilchardus* (20%), and *Penaeus kerathurus* (7%). Changes in fish behavior were reported by 51 respondents (93%), a reduction in fish size by 18%, and changes in fishing seasons by 7%.

Pollution from the Ghannouch industrial zone was frequently cited, along with global warming and sea-level rise (Observed primarily through shifts in terrestrial reference points and the retreat of the shoreline), as contributing factors.

3.4. Marine Biodiversity and Coastal Habitat Changes

Degradation of seagrass meadows (*Posidonia oceanica*, *Cymodocea nodosa*) was reported by 82% of respondents, making it the most widely cited habitat change, with descriptions of reduced meadow extent, increased turbidity, and disappearance of *Ruditapes decussatus*. Extreme weather events (sudden storms, intense swells, jellyfish blooms) were reported by 73% of respondents as having become more frequent or severe.

3.5. Biological Invasions and jellyfish bloom as Climate-Driven Stressors on Small-Scale Fisheries

Biological invasions represented one of the most tangible and economically immediate impacts of climate change reported by fishers in Gabes Governorate. Warming sea temperatures lower thermal barriers that historically constrained thermophilic species, and the shallow, warm coastal waters of the Governorate bordering the Gulf of Gabes create particularly favorable conditions for NIS establishment.

Across all three landing sites, fishers spontaneously and consistently identified non-indigenous invasive crabs (figure 4) and the native jellyfish, whose blooms are amplified by warming, as disrupting their fishing operations, threatening target

populations, and degrading coastal habitats.



Figure 4. Box plots of landed catch quantities (kg per fishing trip) of four non-indigenous species (NIS) recorded by small-scale fishers in Gabes Governorate, Tunisia (2024).

Twelve non-indigenous, recently expanding or harmful species were identified by fishers in Gabes Governorate as causing notable impacts.

Two non-indigenous species, the blue swimming crab *Portunus segnis* and the blue crab *Callinectes sapidus*, and the native but climate-facilitated jellyfish, the mauve stinger *Pelagia noctiluca* were identified as the most economically and operationally damaging, with impacts reported across all landing sites and all experience groups, indicating a well-established and worsening invasion signal.

The results note that the blue swimming crab *Portunus segnis* shows the highest catch quantities and the greatest dispersion (median = 100 kg, max = 1,000 kg). The strongly right-skewed distribution, with multiple high-value outliers, indicates that this Lessepsian invader is already well-established and exploited opportunistically across the fleet, with catch volumes varying widely depending on season, gear type, and fishing ground.

The high IQR reflects heterogeneous fisher engagement with this species, some of them targeting it deliberately with crab traps, others recording incidental catches. Its elevated mean (209.5 kg) relative to its median signals the influence of a small number of very high-catch events, characteristic of aggregating, seasonally abundant invertebrate species. Furthermore, *Penaeus aztecus* displays a comparatively compact and moderately elevated distribution (median = 120 kg, IQR = 92.5 kg), suggesting a species in an active expansion phase whose catches are already economically significant but still reported by a limited subset of fishers.

The relatively symmetric spread implies more consistent catch rates across reporters, consistent with a newly established population showing predictable spatial distribution in the study area.

However, *Metapenaeus monoceros*, reported by only 2 fishermen, has the smallest sample, precluding robust statistical inference. The two observations (20 and 50 kg) suggest occasional, low abundance encounters rather than systematic exploitation, possibly indicating marginal or seasonal presence in the Gabes coastal zone.

Callinectes sapidus shows the lowest catch quantities (median = 3 kg, max = 15 kg) and a tight, low-value distribution. These values are consistent with a species at the early stage of colonization, present in the area but not yet abundant enough to constitute a targeted or economically significant catch. The skew towards very small values (Q1 = 1.9 kg) suggests most encounters are incidental bycatch rather than directed fishing.

3.5.1. Portunus segnis (Blue Swimming Crab)

Portunus segnis, a Lessepsian migrant from the Red Sea now established throughout the central and eastern Mediterranean (Rabaoui et al. 2015, Crocetta et al. 2018, Shaiek et al. 2021, Ben Abdallah et al. 2022, Castriota et al. 2022, Yeşilyurt et al. 2022, Bennici et al., 2025) was the most frequently reported invasive species causing operational

damage to SSF in Gabes Governorate. Fishers across all three landing sites described a marked increase in abundance over recent years, with seasonal peaks in spring-summer coinciding with peak shrimp fishing effort. Per-trip catches of *P. segnis* ranged from 5 to 500 kg, indicating highly variable but potentially harvestable quantities.

Four impact categories were scored on a 0-1 intensity scale:

- Revenue loss / reduced catch efficiency (mean intensity: 0.52 ± 0.18)
- Predation on catches / damage to target organisms inside gear (mean intensity: 0.76 ± 0.11)
- Competitive exclusion of target species from coastal habitats (mean intensity: 0.38 ± 0.15)
- Physical damage to trammel nets and gill nets (mean intensity: 0.91 ± 0.09), the most severe impact

3.5.2 Callinectes sapidus (Blue Crab)

The blue crab *Callinectes sapidus*, native to the Atlantic coast of the Americas and rapidly spreading throughout the Mediterranean (Katselis, and Koutsikopoulos, Shaeik et al. 2021, Corsini-Foka et al., 2021, Öndes et al. 2021, Castoria et al. 2024, Cicala et al. 2025), has been reported in the ports of Ghannouch and Gabes as a species that has recently become established but is increasingly problematic.

Fishermen reported making their first observations around 2020–2021, which corresponds to the documented timeline of its expansion into the Mediterranean and into Tunisian waters (Ragkousis et al. 2020, Shaiek et al. 2021, Ben Abdallah et al, 2022). Among the main impacts are physical injuries sustained by fishermen while retrieving fishing gear and competition with target species of native invertebrates.

The coexistence of *P. segnis* and *C. sapidus* has been described by several interviewees as contributing to a profound restructuring of the coastal invertebrate community.

***3.5.3.** Pelagia noctiluca: A Climate-Driven Native Species*

Pelagia noctiluca bloom events were reported by 31% of fishers as increasingly frequent and severe, typically in summer-autumn. Impacts included: (i) clogging and tearing of nets; (ii) stinging of caught fish, reducing market value; and (iii) skin burns for fishers handling nets. Multiple respondents noted that blooms were absent or rare during their early careers but have become a recurring seasonal nuisance over the past decade, consistent with the acceleration of Mediterranean warming.

3.5.4. Other Species Showing Notable Population Changes

Beyond the three primary NIS/harmful species, fishers reported population changes in several other taxa.

The bluefish *Pomatomus saltatrix* was reported by 6 fishers as increasingly present in coastal waters, possibly reflecting range expansion. The common dolphin *Delphinus delphis* was mentioned by 13 fishers in the context of increased bycatch. The disappearance of the grooved carpet shell *Ruditapes decussatus* was noted by 2 fishers and is consistent with its vulnerability to warming and hypoxia.

3.6. Socioeconomic Impacts

Economic losses attributable to stock declines were reported by 80% of respondents. The most pervasive socioeconomic impact was extreme-weather-related damage, reported by 93% of respondents, including gear damage, hull damage, and forced suspension of fishing activity.

Geographic expansion of fishing zones was reported by 16% of fishers, and changes in fishing gear/technique by 9%. No workforce exits or food security crises were reported.

3.7. Adaptive Strategies

The most frequently cited adaptation measure was the use of crab traps targeting *Portunus segnis* (33% of fishermen), a two-pronged approach that transforms an ecological nuisance into a marketable product while reducing net fouling. The spatial expansion of fishing areas was mentioned by 16% of fishermen, the installation of artificial reefs to protect seagrass habitats by 13%, and a change in gear type by 9%. Suggestions for management measures included the establishment of seasonal biological rest periods, stricter regulations on industrial discharges, and the restoration of seagrass habitats.

4. Discussion

4.1. Limitations of the study

Before examining the substantive findings, it is important to acknowledge the methodological limitations of this study. The sample of 55 respondents, while substantial for a perception-based study in this regional context, does not constitute a statistically random sample of all fishers operating in Gabes Governorate.

The unequal distribution across landing sites (Gabes port: 76%) reflects the proportional fleet composition rather than a sampling artefact, but limits inference to the three ports surveyed. Recall bias is an inherent limitation of retrospective interview-based approaches, mitigated here through anonymity and the use of trained local enumerators familiar with fishing terminology.

The perceived intensity scores (0-1) are subjective and ordinal in nature; although treated as continuous for parametric tests, results should be interpreted with appropriate caution. Future research should triangulate these perceptions with time-series catch data, remote-sensing SST products, independent habitat surveys, and systematic NIS monitoring programs. The questionnaire is provided as Supplementary Material S1 to facilitate reproducibility and independent assessment of instrument design.

4.2. Main findings and implications

Climate change presents key challenges for SSF and mariculture and is projected to have significant impacts on the lives of people dependent on these activities. Changes in ocean temperature and chemistry are already affecting the distribution and abundance of marine organisms.

All respondents reported being aware of climate change. This high level of awareness may be associated with their extensive fishing experience, averaging 21.4 years, which provides a long-term basis for observing changes in the marine environment. The pervasive reporting of stock declines (93%) among fishers (figure 5) of Gabes Governorate is consistent with catch-per-unit-effort trends for key species of the Gulf of Gabes.

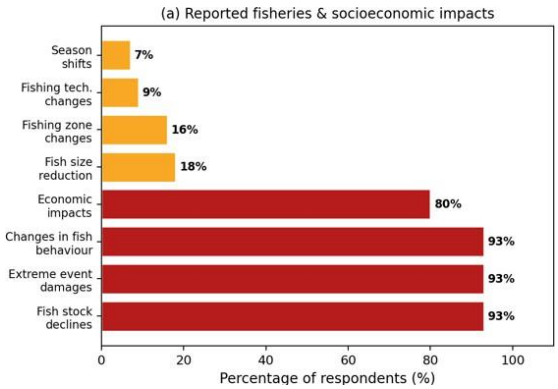


Figure 5. Overview of perceived climate-related impacts on SSF and marine biodiversity among fishers of Gabes Governorate, by thematic category (n = 55 fishers, 2024).

The widely held perception of a rise in SST (75%, average intensity of 0.60) is

consistent with data from the Copernicus Climate Change Service, which reports anomalous global SSTs in 2023-2024, as well as with the documented regional warming of +0.5 to 1.5 °C in the Gulf of Gabes (Bejaoui et al. 2019). The 18% of fishermen who observed a decrease in fish size corroborate the hypothesis of size reduction in ectotherms (Cheung et al., 2013).

The 82% reporting seagrass degradation points to a critical mechanistic pathway linking climate change to fisheries decline: *Posidonia oceanica* meadows support early life stages of many target species, and their degradation under compounding stressors (trawling, eutrophication, thermal bleaching) reduces recruitment potential (Marbà & Duarte, 2010; Telesca et al., 2015).

The prominent role given to biological invasions in fishermen's accounts is undoubtedly the most politically relevant conclusion of this study. Climate change facilitates invasions in multiple ways: warming waters reduce thermal barriers for thermophilic taxa, changes in ocean circulation can accelerate larval dispersal, and the degradation of native communities reduces biotic resistance (Rahel & Olden, 2008; Occhipinti-Ambrogi, 2007).

In the coastal waters of the Gabes Governorate, these mechanisms overlap with the Lessepsian invasion route originating in the Red Sea via the Suez Canal (Galil et al., 2017).

The environmental crisis caused by the Gabes chemical complex is acting as a powerful catalyst for the proliferation of non-native crustaceans. By discharging thousands of metric tons of toxic phosphogypsum and heavy metals daily, the industry has caused massive marine desertification, wiping out nearly 93% of the original biodiversity and severely degrading native Posidonia seagrass beds. This ecological upheaval has left local ecological niches completely vacant, weakening the resilience of the native caramote shrimp.

Taking advantage of this deeply disrupted ecosystem and the silting up of the seabed, highly opportunistic and resilient invasive species, such as *Penaeus aztecus*, have found an ideal environment to colonize the gulf. Industrial pollution has therefore not only destroyed the native fauna: it has literally reconfigured the marine environment, turning it into an ideal habitat for these new colonizers.

The damage caused to nets by *P. segnis* (average impact intensity: 0.91/1) constitutes the most severe operational impact reported, which is consistent with the findings of studies conducted on Turkish and Greek fisheries (Çinar et al., 2011).

Moreover, several fishers reported that *P. segnis* has effectively displaced *Penaeus kerathurus* from portions of its traditional coastal habitat (11-25 m depth) (Ben Mustapha, 1967), while per-trip catches of *P. segnis* ranged from 5 to 500 kg, indicating highly variable but potentially harvestable quantities.

This perception is consistent with documented ecological interactions between established portunid crabs and native penaeid shrimp populations, whereby the superior competitive ability and habitat generalism of invasive portunids reduce the availability of optimal foraging and refuge grounds for native shrimps (Katsanevakis et al., 2014).

The near-complete displacement of *P. kerathurus* from shallow coastal grounds, as perceived by fishers, represents a plausible hypothesis that warrants formal ecological investigation through comparative density surveys before and after invasion establishment.

The rapid spread of *C. sapidus* adds a second species of portunid crab whose impacts overlap but remain distinct.

The spontaneous adoption of crab traps by 33% of fishermen illustrates the adaptive ingenuity of fishing communities and the potential for policies to catalyze this spontaneous response through support for market development.

Jellyfish blooms (*P. noctiluca*), increasingly linked to warm SST anomalies (Boero et al., 2009), represent a distinct, non-commercial stressor that imposes direct operational costs.

The Gabes Governorate is facing a growing proliferation of non-native coastal shrimp, mainly introduced through ships' ballast water or via the Suez Canal. Among these species, the northern brown shrimp (*Penaeus aztecus*), native to the western Atlantic, and the speckled shrimp (*Metapenaeus monoceros*) are expanding rapidly in the gulf.

These exotic species are now being caught in large quantities by artisanal fishermen, particularly using trammel nets between Metouia and Ghannouch, at depths of 5 to 20 meters, where they sometimes take advantage of preserved Posidonia seagrass beds.

Although these new catches represent a significant financial windfall due to their high commercial value on Tunisian markets, their rapid proliferation poses a major ecological threat by competing directly for habitat and food with the famous native caramote prawn (*Penaeus kerathurus*).

The absence of reported workforce exits or food security crises may indicate short-term resilience, but risks masking accumulating vulnerabilities as climate impacts intensify. The low formal uptake of sustainable fishing practices (< 10%) reflects broader governance challenges in Tunisian SSF.

The crab trap response warrants institutional recognition and structured support.

The sample of 55 respondents does not constitute a statistically random sample of all fishermen in the Gabes Governorate. Recall bias and social desirability effects are inherent limitations of this study, though these are mitigated by anonymity and the use of trained interviewers.

The perceived intensity scores (0-1) are subjective; future research should cross-reference these data with time series of catch data, remote sensing data on SST, and systematic monitoring of non-native species (NIS).

5. Conclusion

This study provides the first systematic documentation of climate change perceptions based on surveys among local fishers, with explicit treatment of biological invasions, among small-scale fishers in Gabes Governorate.

Key findings include: (i) near-universal CC awareness and direct observation of environmental shifts; (ii) SST rise as the dominant perceived driver; (iii) near-unanimous concern over fish stock declines and seagrass habitat degradation; (iv) biological invasions (*Portunus segnis*, *Callinectes sapidus*, *Penaeus aztecus* and *Metapenaeus monoceros*) as major invasive stressors, and climate-driven blooms of the native *Pelagia noctiluca*, all causing severe operational and economic impacts; and (v) self-initiated crab trap adoption as a scalable adaptive response. Policy priorities include:

- Formal integration of fisher ecological knowledge into stock assessments and ecosystem-based management.
- Urgent seagrass habitat protection through trawling exclusion zones and industrial discharge regulation near Ghannouch (Gabes Governorate).
- Coordinated NIS monitoring and response frameworks, including

market development for commercial valuable invasive crabs (*Portunus segnis*, *Callinectes sapidus*).

- Early warning systems for jellyfish blooms to reduce operational losses to small-scale fleets.
- Co-management mechanisms formally including fishers in governance processes to enhance adaptive capacity.

Acknowledgments

The authors sincerely thank all fishers who generously shared their time, knowledge and experience.

Supplementary Material

Supplementary Material S1: Survey questionnaire (original French version) is provided as a separate file accompanying this manuscript submission.

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