INDEPENDENT RESEARCH MONOGRAPH

The Mediterranean in Transition

Ecological Reorganisation, Human Pressure and the Local Test of Paros and Antiparos

Bill (Βασίλης) Marangozis
Independent researcher and editor

First edition · July 2026

The Mediterranean in Transition / Η Μεσόγειος που αλλάζει



Publication Note

This independent research monograph synthesises verified scientific literature, historical local records, reproducible mapped estimates, institutional and professional reports, and explicitly bounded author testimony. It does not present new field measurements from Paros or Antiparos. Proposed collection and analysis of new data, including the programme described as Core Stream I, remain an inactive future phase and are not a precondition for the findings presented here.

Paros and Antiparos are treated as a local test of the reach of regional evidence, not as a site for conclusions unsupported by local design. Responsibility for the selection, interpretation and presentation of evidence rests with the author.

Cover photograph: Bill Marangozis — shallow rocky sublittoral habitat at Faragas, southern Paros, Greece (36.98575° N, 25.15706° E), June 2023.

Suggested citation

Marangozis, B. (2026) *The Mediterranean in Transition: Ecological Reorganisation, Human Pressure and the Local Test of Paros and Antiparos*. First edition, July 2026. Independent research monograph.

Abstract

The Mediterranean is undergoing a sustained thermal transition while its ecological communities remain exposed to biological introductions, fishing and other long-standing human pressures. This study examines whether the interaction of climate change, non-indigenous species and fishing pressure is reorganising ecological composition, functions and human relationships with the sea, and how confidently that proposition can be tested around Paros and Antiparos in the central Aegean.

The analysis synthesises verified scientific literature, historical local surveys, mapped habitat estimates, official and institutional records, structured fisher reports and explicitly bounded author testimony. It introduces an evidential framework that separates presence, persistence, spread, measured impact, temporal change and causal attribution, while preserving distinctions among regional exposure, experimentally demonstrated mechanism and local observation. No new field measurements are presented.

Regional evidence establishes a changing thermal regime and shows that warming can alter environmental suitability, extreme exposure and species redistribution. It does not transport organisms or determine ecological outcomes by itself. The rabbitfish case provides strong experimental support for grazing as a mechanism capable of maintaining low-canopy rocky states, but the Paros–Antiparos record does not allocate the condition of local reefs to rabbitfish rather than sea urchins, heat, fishing or direct disturbance. The silver-cheeked toadfish presents a different impact profile: trophic integration, serious toxicity and fishery damage are documented regionally, whereas present local abundance, prey effects and economic loss remain unresolved. Fishing is both a co-driver and a recipient of ecological change, but available Aegean catch series cannot substitute for local, effort-standardised ecological observations.

The Paros–Antiparos corpus is sufficient to reject ecological ignorance. It contains dated baselines, direct station-level observations, mapped habitat, professional reports and one species-specific breeding-colony signal. It remains insufficient to establish a system-wide local trend, functional reorganisation or causal allocation. The appropriate response is an auditable programme of baseline preservation, comparable observation and adaptive management in which precaution is proportionate to risk and every inference remains matched to the scale and design of its evidence.

Executive Summary

Purpose and central question

The Mediterranean is often described as a sea in rapid ecological transition. Its waters are warming; marine heatwaves are becoming more consequential; non-indigenous species continue to be recorded and redistributed; and fishing has altered populations and food-web structure over periods that frequently pre-date systematic observation. These processes are real, but their coexistence does not create a single, self-explanatory narrative. Warming, introduction pathways, establishment, altered grazing, predation, selective removal, habitat disturbance and human adaptation operate through different mechanisms and are measured through different kinds of evidence.

This study asks whether changes in species identity, relative abundance, functional traits and ecological interactions are reorganising the Mediterranean food web, and what those changes mean for the Aegean, the Cyclades and, more specifically, Paros and Antiparos. It does not treat the islands as miniature versions of the basin. They serve as a local test of how far regional evidence, experimental mechanisms and fragmented local observations can legitimately be combined.

The study uses *ecological reorganisation* as an operational concept rather than a synonym for decline. Reorganisation may occur when community composition, functional traits or interactions change, even if local species richness does not fall. Conversely, a longer species inventory, a low ecological-status category or an isolated observation does not by itself establish altered ecosystem function. This distinction places the burden of proof on the transition from occurrence to consequence.

Analytical approach and evidential discipline

The manuscript synthesises peer-reviewed research, regional environmental products, ecosystem and socioeconomic models, historical local surveys, mapped habitat data, institutional records, structured fisher reports and named historical testimony. These sources are evaluated according to what each design can measure. A satellite temperature product may establish regional thermal exposure; an exclusion experiment may demonstrate a grazing mechanism under specified conditions; a local survey may document occurrence at particular stations; an interview may record experienced damage or adaptation. None can silently substitute for the others.

Four evidential thresholds govern the analysis. The first is a documented state: a taxon, habitat condition or human consequence observed under a stated method. The second is temporal change relative to a declared and comparable baseline. The third is functional consequence, requiring evidence that altered identity or abundance changed an ecological interaction, process or human activity. The

fourth is causal attribution, which requires temporal order, a supported mechanism, examination of alternatives and, where feasible, replication, controls or convergence among independent evidence streams.

This framework is deliberately conservative without being dismissive. It protects local knowledge and historical observation from being either over-quantified or discarded. It also prevents uncertainty from being mistaken for stability. A conclusion that the available design cannot identify a local trend is not evidence that no change occurred.

Regional transition: warming, pathways and ecological filtering

The Mediterranean thermal regime has changed over recent decades. Regional satellite and reanalysis studies document long-term surface warming and changes in the frequency, duration and intensity of marine heatwaves. Biological studies also document widespread mortality events and altered seasonal dynamics under combinations of climatic and local anthropogenic pressures. These findings establish regional exposure and demonstrate that thermal change can have ecological consequences. They do not determine the response of every taxon, depth or habitat around Paros and Antiparos.

Warming must also be separated from biological transport. Organisms enter the Mediterranean and Aegean through pathways such as the Suez Canal, shipping and aquaculture. Temperature then acts as one environmental filter among several, influencing survival, reproduction, establishment and spread. A warm-affinity organism cannot establish where it never arrives, and repeated arrival does not guarantee establishment. For this reason, increasing inventories of non-indigenous species record both biological change and the history of detection, validation and taxonomic revision. Presence, establishment, spread and documented impact remain separate propositions.

Regional models reinforce the multi-driver interpretation. Aegean ecosystem dynamics have been represented more successfully when trophic interactions, fishing, temperature and production are considered together. Scenario results are heterogeneous among functional groups and conditional on their assumptions. They are useful for identifying interactions and possible nonlinear responses, not for forecasting a particular Parian bay or assigning a fixed causal share to climate or fishing.

Grazing and the rabbitfish case

The first detailed functional case concerns herbivory. In July 2011, *Siganus luridus* was recorded at all 14 shallow stations surveyed around Paros and Antiparos and was described as the dominant herbivorous fish observed. Extensive barrens were recorded during the same campaign. The conjunction is ecologically significant, but the survey did not measure rabbitfish biomass, bite rates, sea-urchin

abundance, algal production or temporal change. It therefore establishes co-occurrence rather than causation.

Experiments elsewhere in the eastern Mediterranean show that grazing fishes can maintain low algal biomass on established barrens, while northern Aegean experiments demonstrate that native sea urchins can perform the corresponding role under different conditions. Regional comparisons associate rabbitfish and urchins with reduced canopy or erect algae, but they also reveal strong dependence on geography, habitat, depth and consumer assemblage. Grazing may prevent recovery after heat, physical disturbance, sedimentation or another pressure has removed the canopy. The mechanism responsible for maintaining a barren need not be the mechanism that created it.

Four later rocky stations within the Paros–Antiparos system received mean vegetation-restricted reef-EBQI classifications of “Bad”. These are direct, method-specific observations of macroalgal status at those stations. They are not a repeated survey of the 2011 locations, an island-wide reef assessment or evidence that rabbitfish caused the measured condition.

The local grazing hypothesis is consequently strong enough to test and too incomplete to declare. A decisive design would align rabbitfish, native herbivores and sea urchins with grazing activity, benthic structure, recruitment, temperature, habitat and competing pressures. Repeating historical stations could establish persistence or change in detection, but it would not establish causation on its own.

Silver-cheeked toadfish: trophic, toxicological and operational impact

Lagocephalus sceleratus presents a different evidential structure. Diet studies establish that it is a high-trophic-level consumer in sampled eastern Mediterranean populations, but stomach contents do not demonstrate a prey-population decline or a reconstructed food-web effect. Toxicological evidence is more direct: tetrodotoxin and its analogues have been detected in multiple tissues, including muscle, and European rules prohibit products derived from poisonous Tetraodontidae from being placed on the food market. Public-health protection therefore does not require proof of a basin-wide ecological effect.

Fishery damage is also directly documented in selected Greek waters through onboard observation and structured interviews. The magnitude varies sharply by geography, gear and fishing practice. Regional cost estimates cannot be multiplied across the Parian fleet, and adaptation may reduce recorded repair costs while increasing fuel, time, displacement or forgone catch.

The Greek call issued in June 2026 for a possible targeted-removal pilot in Crete and the South Aegean illustrates the distinction between programme design and programme outcome. A payment per kilogram may support fishers, produce samples and remove toxic biomass. Kilograms delivered do not establish population suppression, ecological recovery or equitable compensation. Those outcomes

require independent abundance indicators, pre-intervention baselines, standardised effort, safe chain-of-custody records and separate ecological and livelihood evaluation.

Around Paros and Antiparos, the species had been reported before 2011 but was not detected in the 14 shallow stations during that campaign. This protocol-specific non-detection does not establish absence from deeper or different habitats. Present local abundance, diet, prey effects, annual cost and the outcome of any future intervention remain unknown.

Fishing as a co-driver and the problem of the denominator

Fishing is not merely a sector affected by ecological change. It selectively removes organisms, alters population size and age structure, redistributes effort and changes the ecological context in which warming and non-indigenous species operate. Yet the claim that “fish are becoming smaller” can refer to at least four different quantities: individual growth and maturation, population size structure, maximum observed length or catch composition. These quantities require different observations and do not share a universal physiological explanation.

Fishery-independent studies outside the Aegean show that temperature and fishing pressure can carry joint information about the size structure of some exploited fishes, but responses differ among taxa. Spatial syntheses and laboratory experiments likewise reject a single rule that converts warming into a fixed reduction in fish size. Their results motivate local hypotheses; they do not supply local effect sizes or forecasts.

Aegean landing indicators and the later Greek catch reconstruction show a long-term change in catch composition and demonstrate that earlier official statistics omitted substantial components, especially from small coastal vessels. The reconstructed series remains an estimate with explicit assumptions, and it cannot resolve local biomass, fishing mortality or the contribution of professional, recreational, discarded and informal removals around Paros.

The central local deficit is therefore a missing denominator. There is no aligned series of habitat-specific fish size and abundance, professional and recreational effort, catch per unit effort, removals, temperature and habitat condition. Historical testimony can identify places, practices and plausible changes, but it cannot manufacture these denominators retrospectively.

Human consequences and distribution

Ecological change becomes an economic or social consequence only through an affected bearer, place, period and counterfactual. A damaged net, altered catch, food-safety requirement, degraded habitat or new market opportunity belongs to a different ledger. Landed value, revenue, profit, household income,

value added and public expenditure are not interchangeable, and turnover at successive stages of a value chain cannot be added without double counting.

Adaptation is similarly ambiguous. Changing grounds or gear may reduce visible damage while increasing fuel, labour or risk. A new edible non-indigenous species may create value for some participants without demonstrating ecological benefit. Compensation can support a fisher while remaining a public transfer rather than a net social gain. Markets also omit habitat integrity, cultural attachment, public-health protection and the option of passing a functioning ecosystem to future generations.

For Paros and Antiparos, no verified local series currently connects ecological state to vessel effort, catch, damage, price, household welfare, tourism-facing value chains and public cost. A credible account would require linked but separate vessel, transaction, household and public ledgers. Distribution must be examined before aggregation because gains and losses that cancel arithmetically may remain socially and politically consequential.

The Paros–Antiparos evidence mosaic

The local corpus contains more evidence than a narrative of ecological ignorance would suggest. Its strongest objects include:

- the protocol-defined 2011 survey of 14 shallow stations;
- older and later rocky-reef observations, including four station-level macroalgal assessments;
- a 2020 Pantieronisi cave record, including an ovigerous *Urocaridella pulchella*;
- historical seabird monitoring, including a documented local decline and later absence of the Audouin's-gull breeding colony approaching 2012;
- an auditable extraction of approximately 36.8 square kilometres of mapped seagrass-category polygons within the project's declared bounding box;
- structured professional-fisher reports from a national study that included Paros; and
- named historical testimony identifying locations and changes worthy of formal investigation.

These objects do not form a common time series. They differ in habitat, depth, date, season, method, effort and measured variable. The mapped seagrass area is not a measure of present healthy *Posidonia oceanica* or trend. The cave record establishes presence and reproductive condition, not persistence or impact. The seabird record contains a genuine species-specific temporal signal, but not a direct index of underwater prey abundance. Professional reports document experience, not island-wide catch per unit effort or annual loss.

The resulting local conclusion is narrow but substantial. The record is sufficient to reject ignorance and to identify ecologically consequential elements of regional change within the island system. It is not sufficient to establish a representative present condition for all principal habitats, a system-wide temporal reorganisation, a reconstructed local food web or the relative contribution of warming, non-indigenous species, fishing, sea urchins, anchoring, development, water quality and other pressures.

Research, management and the meaning of uncertainty

The study's proposed response is not an indiscriminate expansion of monitoring. It is a staged evidence architecture. Historical stations, methods, taxonomic decisions and raw materials should first be preserved and recovered. Pilot work should estimate detectability, observer effects and realistic precision. Repeated station-based observation can then establish trajectories at supported sites, while a spatially balanced habitat frame is required for representative present-condition estimates. Interventions should be evaluated against explicit ecological, livelihood, safety and distributional objectives.

The 14-station survey from 2011 and the four later rocky-reef stations must remain distinct analytical panels. A future visit to the published 2011 coordinates should be described as a historical-coordinate resurvey unless route geometry and observer procedures can be recovered. Improved technologies may be added as an enhancement lane, but they should overlap with historical methods long enough to quantify any break in measurement.

Management need not wait for complete causal reconstruction when credible harm may be serious or irreversible. The evidential threshold for a reversible precautionary measure can be lower than the threshold for a definitive causal claim. Public-health communication about poisonous fish, temporary protection of a sensitive habitat or rapid verification of a harmful taxon may be justified while investigation continues. Costly, coercive or irreversible measures require stronger evidence and explicit review rules.

The principal conclusion is therefore neither a prediction of ecological collapse nor an assurance of stability. The Mediterranean and Aegean contexts are changing, and local evidence shows that Paros and Antiparos are already connected to that transition. What remains unresolved is the magnitude, trajectory and causal composition of system-wide local change. The scientifically defensible response is sustained, comparable and decision-linked enquiry, combined with proportionate action where the expected cost of delay exceeds the cost of reversible precaution.

Contents

- Abstract
- Executive Summary

1. A Familiar Sea, an Incomplete Record
2. What Ecological Reorganisation Means
3. From Arrival to Impact
4. When Grazing Changes
5. Silver-Cheeked Toadfish: A Different Kind of Impact
6. Fishing as a Co-Driver
7. From Ecology to Human Consequences
8. Paros–Antiparos: A Local Test, Not a Local Verdict
9. A Research and Management Agenda under Uncertainty

- Conclusion: A Changing Sea and the Discipline of Knowing

Chapter 1 — A Familiar Sea, an Incomplete Record

The sea between Paros and Antiparos is familiar enough to invite certainty. It is watched from beaches, crossed by fishing boats and ferries, entered by swimmers and divers, and remembered across generations. Such familiarity is valuable, but it is not the same as measurement. Human observation tends to preserve the exceptional and normalise the gradual. A once-conspicuous species may quietly become scarce; another may become ordinary before anyone thinks to record when it arrived. Even careful memory has no fixed sampling effort, constant depth or control site. The scientific problem is therefore not whether people have noticed change. It is whether the surviving record can distinguish ecological change from changes in the conditions under which the sea has been observed.

This distinction matters particularly in the Aegean. Separate bodies of evidence document a changing Mediterranean thermal regime, long-term shifts in Aegean demersal-resource composition, changes in plankton seasonality at a monitored eastern Mediterranean site and an expanding, repeatedly revised inventory of recorded non-indigenous species (Damalas et al., 2021; Kalloniati et al., 2023; Hamdeno and Alvera-Azcárate, 2023; Zenetos et al., 2025). These findings do not describe one uniform transformation. They concern different organisms, depths, periods and spatial scales; they were obtained through different instruments and designs; and they do not assign every observed change to the same cause.

The temptation is nevertheless to combine them into a single narrative: the sea is warming, unfamiliar species are appearing, fish are becoming scarcer, and the ecosystem is therefore in general decline. The narrative is intuitively coherent, but coherence is not causal proof. A satellite-derived surface temperature, a diver's quadrat, a fisher's account, a landings reconstruction and a modelled food web may each be valid for its purpose. None is interchangeable with the others.

Climate change and biological invasions are also not acting on an ecological blank slate. Mediterranean food webs have been exposed to decades of selective removal, only partly captured by official fisheries statistics (Touloumis et al., 2026). This does not establish how much fishing contributed to any particular observation around Paros. It makes fishing pressure a co-driver to be examined alongside climatic forcing and non-indigenous species, rather than a secondary issue introduced only after ecological change has been described. These are the study's three organising axes, not an exhaustive inventory of pressures. Nutrient change, habitat disturbance, pollution, anchoring, coastal construction and shifts in primary production remain part of the explanatory field wherever the evidence requires them.

The central question is therefore not simply whether the Aegean is changing. It is whether changes in the identity, abundance, distribution and interactions of organisms are altering ecological function, and how confidently that proposition can be tested around Paros and Antiparos.

A Local Mosaic

Paros and Antiparos are not treated here as miniature versions of the Mediterranean. They form a demanding local test case: sufficiently observed to rule out complete ignorance, but too discontinuously monitored to sustain a simple account of system-wide change. The evidence is best understood as a mosaic of observations separated by habitat, depth, date, method and purpose.

The clearest protocol-defined local reference is the July 2011 rapid assessment of conspicuous shallow-water alien megabiota. Fourteen stations were surveyed for one hour each at depths of 0–10 metres. Eight taxa classified as alien in the original study were recorded; *Siganus luridus* occurred at all 14 stations and was described as the dominant herbivorous fish (Katsanevakis, 2011). The study establishes historical occurrence under a specified design. It does not show how abundance subsequently changed, and the co-occurrence of rabbitfish and extensive barrens does not by itself identify the cause of those barrens.

Later records address different ecological objects. Four rocky stations were assessed through photographic quadrats and a macroalgal-community-based index; their mean vegetation-restricted reef-EBQI values fell within the category labelled “Bad” for the sampled stations and period, not for every rocky shore around the islands (Savin et al., 2023). A 2020 observation from the Pantieronisi marine cave documented two individuals of *Urocaridella pulchella*, including an ovigerous female; this establishes presence and reproductive condition at that time, not recruitment or a self-sustaining regional population (Digenis et al., 2021; Digenis et al., 2025).

Mapped habitat and fisher knowledge add other forms of information. A reproducible extraction from the SEANOE seagrass dataset identified approximately 36.8 square kilometres of non-overlapping polygons classified as seagrass habitat within a declared bounding box around Paros, Antiparos and neighbouring islets (author’s calculation from Panayotidis et al., 2022b; see Methods Appendix 8A). The calculation provides a spatial reference, not a measurement of present ecological condition, species identity, density or trend. A 2025 study of professional fishers across seven Greek ports also included Paros and recorded local reports of interactions with non-indigenous species and gear damage associated with *S. luridus* (Moutopoulos et al., 2025). Such reports can reveal recurrent phenomena that short campaigns miss, but they do not yield a calibrated local estimate of abundance, catch per unit effort or annual loss.

These records correct two opposite errors. The area is not without scientific evidence. Nor do its scattered observations constitute a monitoring time series. The 2011 survey, later reef assessments, cave records, habitat maps and fisher reports do not measure the same variables over comparable sites and periods. They can establish historical states, identify plausible mechanisms and direct future enquiry. They cannot be arranged into a trend merely because they refer to the same islands.

Chapter 8 provides the full source-level audit, including additional records from Despotiko, Strongylo, north-eastern Paros, local seagrass products, seabird monitoring and bounded historical testimony. The purpose of introducing the mosaic here is narrower: to make clear from the outset which propositions are measured locally and which depend on regional inference.

From Regional Evidence to Local Inference

Regional evidence is indispensable because the local record is incomplete, but geographical proximity does not guarantee equivalence. A Cycladic comparison may be close in space while differing in substrate, exposure or fishing pressure. A Levantine experiment may identify a grazing mechanism convincingly while remaining unable to estimate its magnitude around Paros. A sea-surface-temperature product may describe the thermal history of a grid cell while only indirectly representing a sheltered meadow or a cave at depth.

Every proxy must therefore be judged against the quantity being inferred. Variable, unit, habitat, depth, season, organism, sampling method, causal design and uncertainty all matter. These dimensions should not be collapsed into a single score. One critical mismatch can be enough to prevent quantitative transfer even when other features correspond closely.

The study consequently uses external evidence in two different ways. Where the design is strong, it may establish that a mechanism operated under the conditions actually studied. Where geography and ecological context are relevant but not equivalent, it may support a plausible direction of change or a testable local hypothesis. It is used to estimate present conditions around Paros and Antiparos only when correspondence with the target quantity is demonstrably close.

This discipline defines the study’s central boundary. The assembled evidence supports a changing regional thermal and ecological context and documents several historical local states. It does not reconstruct a complete present-day food web for Paros and Antiparos, demonstrate a local system-wide temporal reorganisation, or partition the relative contributions of warming, fishing, grazing, pollution, anchoring and coastal development.

That conclusion is not a finding of ecological stability. It is a statement about the reach of the available designs. Ecological reorganisation may occur without a systematic decline in species richness, because community composition and interactions can change even where species counts remain similar

(Dornelas et al., 2014; Pecl et al., 2017). Yet it should not be inferred merely because a non-indigenous species has been recorded or an ecological index has returned a low-status category. Before asking whether a familiar Aegean sea is becoming a different ecological system, the analysis must specify what would count as reorganisation, relative to which baseline, and with what standard of evidence. That is the task of the next chapter.

Chapter 2 — What Ecological Reorganisation Means

The language used to describe ecological change is rarely neutral. Terms such as *degradation*, *regime shift* and *reorganisation* can appear to explain a system before the evidence has established what changed, when it changed or why. In this study, *ecological reorganisation* is neither a synonym for general decline nor the name of a standardised index. It is an operational term that specifies the kinds of change that would justify describing the ecological organisation of a familiar sea as different.

For the purposes of this analysis, **ecological reorganisation means a change in the identity or relative abundance of species, in the distribution of functional traits, or in ecological interactions**. It does not require every native species to disappear. It is not disproved merely because the number of species at a site remains stable. Nor does it identify its own cause. Warming, fishing, nutrient change, habitat disturbance and the arrival or expansion of non-indigenous species may act separately or together; the term *reorganisation* does not decide among them.

This definition imposes a sequence on the argument. Redistribution may alter community composition, and compositional change may have functional consequences. Neither transition is automatic. Species can shift their distributions without becoming locally abundant; abundance can change without a measured alteration in grazing, predation, production or energy flow. Conversely, ecological function may change before a dramatic loss of species becomes visible. The task is to keep these dimensions analytically separate and then test the links among them.

Richness, Composition and Function

Species richness is the number of species recorded within a defined place, period and sampling design. Composition asks which species are present and, where the data permit, how their relative abundances are distributed. Function concerns what organisms do and how their activities shape ecological interactions and processes. These dimensions may move together, but they need not.

Dornelas et al. (2014) compared 100 ecological assemblage time series containing 35,613 species. They found no systematic mean trend in local species richness across the assembled datasets, yet Jaccard similarity declined in 79 of the 100 time series, indicating widespread compositional turnover. The result does not imply that biodiversity loss is absent, that every locality follows the average or that turnover is harmless. It establishes a narrower point: an assemblage may change substantially even when its species count shows no corresponding systematic trend.

Climate-driven redistribution provides one route through which turnover can acquire functional significance. Species do not shift at the same speed, in the same direction or with the same demographic

success. Asynchronous responses can create new combinations of predators, prey, competitors and habitat-forming organisms, with consequences for ecological processes and human well-being (Pecl et al., 2017). Redistribution supplies a plausible mechanism; it neither guarantees a common outcome nor establishes what has occurred at a particular Aegean site.

Species richness is therefore inadequate as a diagnostic on its own. A site might retain the same number of species while a canopy-forming alga becomes scarce and turf expands, or while the relative abundance of herbivores changes. The count would remain stable while the ecological configuration changed. The reverse caution is equally important: compositional turnover is not, by itself, proof of altered function. Functional change requires evidence that altered identity, abundance or traits changed an interaction or process.

Food-Web Structure and Multiple Drivers

A food web is treated here as a network of flows of matter and energy connected through direct and indirect trophic interactions. It is not a simple ladder with one producer at the bottom and one predator at the top. Producers, detritus, plankton, benthic invertebrates, fishes, higher vertebrates and fisheries may be joined through several pathways. A change in one component can propagate beyond the organisms directly involved, but its direction and magnitude depend on the structure of the network.

This is why bottom-up and top-down processes are useful distinctions but poor rival slogans. Changes in nutrients, primary production or plankton seasonality can alter the resource base available to consumers. Changes in predation, fishing or grazing can alter organisms lower in the web. These pathways interact, and other relationships may dampen, amplify or redirect their effects.

The long record from the inner Saronic Gulf illustrates the problem of attribution even where monitoring is unusually sustained. Across 631 fortnightly samples, Kalloniati et al. (2023) observed changes in plankton biomass and seasonality during a period that combined warming with reduced anthropogenic nutrient loading following improved wastewater treatment. The later period was warmer and less mesotrophic, with earlier zooplankton growth, closer seasonal synchrony with phytoplankton and an additional autumn growth period. The study did not isolate warming as the sole cause or measure a complete trophic cascade. Its value lies in showing how apparently coherent biological change can emerge under simultaneous climatic and local anthropogenic shifts.

For the Aegean as a whole, a static Ecopath model offers a quantitative anatomy rather than a direct observation of change. Keramidas, Dimarchopoulou and Tsikliras (2022) represented 201,535 square kilometres through 44 functional groups, describing a mass-balanced mean annual state for 2003–2006 with important benthic and benthopelagic energy pathways. The model is an internally coherent

representation under its data and assumptions. It is not a map of the present-day Cyclades or a locally parameterised description of Paros and Antiparos.

The distinction clarifies the burden carried by the phrase “a new food web”. A local food-web reconstruction would require information on biomass, production, consumption, diet and fisheries removals across interacting groups. Demonstrating change would require comparable information through time, or another design capable of identifying altered interactions or flows. The local record introduced in Chapter 1 documents occurrence, selected community states, mapped habitat and participant reports. It does not meet that heavier evidential threshold.

Regional models also caution against single-driver interpretation. A historically fitted ecosystem model of the northern Aegean reproduced observed dynamics more successfully when trophic interactions, fishing, sea-surface temperature and primary production were considered together (Tsagarakis et al., 2022). A later Aegean model produced heterogeneous and nonlinear responses among functional groups under combinations of fishing and warming; non-indigenous species were excluded because consistent official catch series were unavailable (Keramidas et al., 2024). At Mediterranean scale, an end-to-end model under a high-emissions scenario projected different ecological winners and losers among species and subregions rather than a uniform basin-wide response (Moullec et al., 2019). These are conditional model results, not forecasts for Paros. Their common lesson is that ecological change should not be expected to proceed in one direction, at one rate, for every component.

Baselines and the Uses of Memory

Any claim of reorganisation is relative to a baseline. A baseline is a stated reference against which change is assessed; it need not be pristine, natural or desirable. A survey conducted after decades of fishing may still be a valid measurement baseline if its date, method and limitations are explicit. It cannot silently become a reconstruction of conditions before those pressures began.

Pauly (1995) used the term *shifting baseline syndrome* to describe how successive generations of fisheries scientists may accept the stock size and species composition encountered early in their careers as normal, even when these already reflect earlier depletion. The concept does not establish an historical abundance for Paros. It identifies a systematic risk in how environmental memory is converted into a reference condition.

Sáenz-Arroyo et al. (2005) provided an empirical test in a different ecological and social setting. In structured interviews with 108 fishers from three generations in 11 Gulf of California communities, older fishers identified more depleted species and grounds and recalled larger historical maximum catches. The findings support intergenerational differences in remembered conditions. They do not supply ratios

transferable to the Aegean, and they remain vulnerable to retrospective memory, cohort effects and changes in gear or fishing experience.

The appropriate response is neither to romanticise memory nor to discard it. Long experience at sea can reveal former grounds, changes in seasonality, practices omitted from official records and questions overlooked by short scientific campaigns. Memory nevertheless lacks constant effort, fixed gear and predetermined spatial design. It should be retained as a distinct evidential class and compared, where possible, with logbooks, landings, photographs, specimens, surveys and environmental records.

The author's long-term observations are governed by the same rule. They are historical and social testimony, not a quantitative time series or independent validation of an ecological trend. Their value lies in identifying recording gaps and generating hypotheses that structured evidence can test.

For Paros and Antiparos, the 2011 rapid assessment is therefore a protocol-defined historical reference for the taxa and habitats detectable by that design. It is neither a pristine baseline nor evidence of present conditions. Later reef assessments, cave observations and fisher reports contribute other measurements, but differences in site, method, depth, season and variable prevent their conversion into an artificial time series. The possibility of a shifting human baseline increases the value of renewed measurement; it does not license the inference of missing values.

What Would Count as Evidence?

Because *ecological reorganisation* is used operationally, the study adopts four evidential thresholds. They are analytic rules for this manuscript, not a universal hierarchy applicable to every ecosystem.

The first threshold is **documented state**. A record must identify what was observed, where, when, in which habitat or depth, and by which method. It can establish occurrence, abundance within a sample or the value of a specified indicator. A single campaign cannot normally establish temporal change.

The second is **compositional change**. This requires comparable observations through time, or another design able to distinguish changes in identity, relative abundance or functional-trait structure from changes in sampling and detectability. A new record may reflect arrival, delayed recognition or greater search effort. Richness alone is insufficient because replacement and altered dominance can occur without a change in species count (Dornelas et al., 2014).

The third is **functional change**. Evidence must concern an ecological role, interaction or process, such as measured grazing, predation, production, recruitment, habitat formation or a quantitatively constrained flow of biomass or energy. Experiments, observations and models answer different questions. An experiment may isolate a mechanism under specified conditions; an observational design may identify a

pattern; a model may test internal coherence and explore conditional consequences. None should be described as stronger than its design permits.

The fourth is **causal attribution**. Assigning change to warming, fishing, a non-indigenous species or another pressure requires more than coincidence. The proposed cause must precede the response at the relevant scale, a plausible mechanism must be supported and serious alternatives must be examined. Replicated experiments, controls, comparable time series and convergence among independent lines of evidence can strengthen attribution. Models can evaluate the joint plausibility of drivers, but fitting a historical pattern does not prove that the included drivers are the only causes.

These thresholds clarify the status of the Paros–Antiparos record. The local evidence crosses the threshold of documented state for several taxa, habitats and stations. It generates testable hypotheses about grazing, benthic condition, thermal exposure and fisheries interactions. It does not yet demonstrate a local temporal reorganisation of community composition, a reconstructed change in food-web function or a partition of causes. This does not establish ecological stability. It defines what the assembled evidence is capable of testing.

The next chapter moves from criteria to mechanism. It separates transport, survival, establishment, spread and ecological impact; treats warming principally as an environmental filter rather than an introduction pathway; and asks what evidence is required at each transition (Blackburn et al., 2011; Katsanevakis et al., 2014). This sequence prevents presence from being mistaken for impact and correlation from being mistaken for cause.

Chapter 3 — From Arrival to Impact

The transition from definition to mechanism is often compressed into a deceptively simple story: the Mediterranean warms, tropical species arrive through the Suez Canal, and native ecosystems deteriorate. Each element refers to a real process. Their compression into one causal chain is the problem.

Organisms are transported through particular pathways. They then encounter physical and biological conditions that may permit or prevent survival. Some reproduce and form self-sustaining populations; some of those spread beyond the locations where they were first introduced or detected. Ecological impact is a further proposition, requiring evidence of a changed population, interaction, ecological process or human consequence. Arrival, establishment, spread and impact are therefore not stations on a conveyor belt that every organism passes in sequence. They are separated by barriers, contingencies and distinct burdens of proof (Blackburn et al., 2011).

This distinction is particularly important in the eastern Mediterranean, where a changing thermal regime, an open biogeographical corridor, intense shipping and long histories of fishing and coastal use operate together. Warming may increase the probability that a warm-affinity organism survives and expands. It does not carry the organism through a canal, in ballast water or on a hull. Conversely, repeated transport can deliver propagules without ensuring establishment. The route by which an organism arrives must be distinguished from the conditions that determine what happens afterwards.

3.1 A Changing Thermal Regime

Long-term warming and a marine heatwave describe different aspects of thermal change. The first is a shift in the underlying temperature distribution over years or decades. The second is an extreme event defined relative to a seasonally varying local climatology. Under the widely used hierarchy proposed by Hobday et al. (2016), a marine heatwave occurs when temperature exceeds a seasonally varying 90th-percentile threshold for at least five consecutive days. The reference climatology and baseline period are integral to the definition. A hot week in August is not a marine heatwave merely because its absolute temperature is high; it qualifies when it is anomalous relative to the conditions normally expected at that place and time of year.

The choice of baseline also affects interpretation. A fixed historical baseline can show how extremes change relative to an earlier climate, while a moving baseline may progressively normalise part of the warming signal. Counts derived from different climatologies should not be compared as if they measured the same quantity.

For the Mediterranean, satellite and reanalysis products show changes in both the background regime and its extremes. Hamdeno and Alvera-Azcárate (2023) estimated increasing trends in sea-surface temperature and in the frequency and duration of marine heatwaves over 1982–2020. Their analysis of the 2019 events also showed marked variation among sub-basins in timing, intensity and vertical extent. In the eastern Mediterranean reanalysis examined by the authors, anomalies extended below the surface rather than remaining confined to the satellite-observed surface layer.

Denaxa et al. (2025) separated the contribution of long-term mean warming from interannual variability in Mediterranean surface marine-heatwave trends over 1982–2023. Mean warming dominated trends in maximum intensity, the occurrence of more extreme events, longer exposure and annual cumulative heat stress. Trends in mean marine-heatwave intensity were more sensitive to interannual variability and to the climatological baseline. Chronic warming and extreme-event variability are therefore analytically distinct even when both shape the thermal regime.

Subsurface anomalies do not make surface temperature interchangeable with habitat-specific exposure. A satellite pixel estimates the surface state over a spatial cell. It does not directly record the temperature experienced by a gorgonian on a wall, a seagrass meadow at 15 metres or a mobile fish crossing exposed and sheltered habitats. Wind, stratification, currents, mixing, bathymetry and local geometry can make nearby sites thermally different. Regional surface products provide essential historical context; biological attribution at depth requires observations at the depth and habitat where the response is inferred.

Future projections require another distinction. Mediterranean regional-climate simulations project a strong intensification of large summer marine heatwaves under high emissions, with scenario differences becoming especially consequential after mid-century (Darmaraki et al., 2019). These are conditional simulations, not dated forecasts for a particular bay. They indicate how risk changes under specified emissions and model assumptions; they do not predict the temperature or ecological outcome of a named future event at Paros.

Regional sea-surface and reanalysis products therefore place Paros and Antiparos within a changing thermal and oceanographic setting. They do not reconstruct the exposure of every inlet, reef, cave or seagrass meadow. The asymmetry is important: regional thermal change is well supported, while the fine-scale thermal history of the local habitats remains largely unmeasured.

3.2 Exposure Is Not Effect

Physical exposure is part of a climate-impact argument, but it is not the biological effect itself. Between a thermal anomaly and ecological reorganisation lie several possible responses: physiological stress, altered behaviour, reduced growth or reproduction, mortality, changes in recruitment, shifts in relative

abundance and, in some cases, changed interactions or ecosystem processes. Evidence at one level cannot be assumed to establish all those that follow.

The Mediterranean record of mass mortality illustrates the distinction. Garrabou et al. (2022) assembled mortality surveys across 142 monitoring areas, basin-scale satellite data and a smaller in situ temperature network. During 2015–2019, 78% of the monitored areas recorded mortality affecting at least one taxon in at least one year. Within the north-western Mediterranean subset used for heat-exposure analysis, mortality incidence was significantly related to the number of marine-heatwave days. The study documents recurrent, geographically extensive biological disturbance associated with heatwaves. It does not show that every event produced mortality at every site, that all taxa responded equally or that the same effects occurred around Paros.

Mass mortality can alter populations and benthic communities, particularly when long-lived habitat-forming organisms recover slowly. Even a severe mortality event does not, on its own, reveal how the food web subsequently changed. Functional reorganisation would require evidence that losses persisted, recruitment changed, competitors or consumers responded and ecological processes were consequently altered. Mortality may initiate a longer sequence; it does not document every step in that sequence.

Long records and ecosystem models expose a different difficulty. Biological change may be well measured while its causes remain entangled. The Saronic plankton record combined warming with reduced nutrient inputs (Kalloniati et al., 2023). Six decades of fishery-derived Aegean demersal indicators were also influenced by effort, gear, targeting, regulation and markets (Damalas et al., 2021). Aegean ecosystem models produced heterogeneous responses when trophic interactions, fishing, temperature and primary production were considered together (Tsagarakis et al., 2022; Keramidas et al., 2024). Collectively, these studies support a multi-driver interpretation, not a uniform climate response or a forecast for the Cyclades.

The progression from exposure to effect can therefore be expressed as a sequence of tests. Was the relevant organism or habitat exposed at the relevant depth, intensity and duration? Was a physiological or demographic response measured? Did it alter abundance or community composition? Did the change persist long enough to modify an interaction or process? Were serious alternative drivers examined? The sequence does not weaken the climate signal. It specifies what must be observed before the signal can be assigned a particular ecological consequence.

3.3 Labels Mark Different Ecological Claims

The vocabulary of biological invasion can create a false impression of categorical certainty. *Non-indigenous*, *established*, *spreading* and *impact-documented* describe different ecological properties.

The framework proposed by Blackburn et al. (2011) separates movement beyond a native range from introduction into the wild, survival, reproduction, establishment and spread beyond the area of introduction. Barriers occur between these states, and a species may fail at any one of them. Within that framework, *invasive* refers to spread; it does not automatically mean that ecological damage has been demonstrated. Other scientific, legal and policy systems reserve *invasive* for organisms associated with harm. The term is therefore informative only when its intended meaning is stated.

In this study, a **non-indigenous species** occurs outside its historically natural range through direct or indirect human agency. An **established population** is self-sustaining through reproduction and recruitment without repeated introduction. A **spreading population** has expanded beyond the location or restricted area of introduction. An **impact-documented species** has empirical evidence linking it to a measured ecological, economic or health consequence under defined conditions. These properties may coincide, but none should be inferred merely from first detection.

Blackburn et al. (2014) formalised the separation between occurrence and consequence by classifying environmental impact from Minimal to Massive while retaining Not Evaluated and Data Deficient categories. The framework classifies documented consequences, not mere occurrence or spread. An impact category reported elsewhere is not a prediction for Paros.

The same discipline applies to **tropicalisation**. Tropicalisation is an increase in the relative importance of warm-affinity organisms, traits, interactions or functions as distributions and abundances change. It may involve non-indigenous species entering from warmer regions, but it may also involve native thermophilic species expanding or becoming more abundant. A longer inventory of non-indigenous species does not by itself demonstrate functional tropicalisation, just as a warmer assemblage need not consist only of foreign species (Raitsos et al., 2010; Moullec et al., 2019; Santana-Garcon et al., 2023).

Mediterranean impact evidence is correspondingly uneven. Tsirintanis et al. (2022) found negative and positive effects across biodiversity, ecosystem services and human health, but the evidence was concentrated in a subset of species and varied substantially in strength and type. Absence of a documented impact is not proof of harmlessness, especially for poorly studied taxa. A plausible effect nevertheless remains distinct from a measured one.

3.4 Counting Records Is Not Counting Arrivals

Inventories are indispensable. Without validated names, dates and locations, neither spread nor policy response can be assessed. Yet an inventory is a record of detection and validation as well as a history of biological change. Its growth cannot be read directly as an introduction rate.

The corrected Mediterranean inventory assembled by Zenetos et al. (2022) contained 1,001 validated non-indigenous species recorded by December 2021, of which 759 were classified as established. These

are counts under the taxonomy, validation rules, geographical scope and reference date of that assessment and its corrigendum. They do not imply that 1,001 self-sustaining populations occurred everywhere, that all produced measurable effects or that change from an earlier list equalled population growth.

The updated Aegean inventory provides a closer frame. By August 2024, 342 non-indigenous species had been validated for the Aegean, with 281 recorded in the South Aegean (Zenetos et al., 2025). The pattern is consistent with proximity to the Levantine basin and exposure to several transport and dispersal pathways. It remains a record of validated occurrence, not a census of abundance, biomass or ecological effect.

First records are shaped by search effort. A species may remain undetected because it is rare, cryptic, seasonal, deep, difficult to identify or present in an unsurveyed habitat. Detection may follow specialist re-examination, a citizen-science image, molecular discrimination or sampling in a new locality. Publication may lag detection; taxonomic or origin status may later be revised. Harmonised inventories are required precisely because national and regional lists otherwise differ in rules and timing (Galanidi et al., 2023).

A rising validated inventory therefore demonstrates that the known non-indigenous biota is being enlarged and revised. Combined with independent pathway and distribution evidence, it may also be consistent with continuing introduction and spread. The inventory alone cannot partition new biological arrivals, delayed detection, greater effort, taxonomic revision and improved information exchange. A first publication date is a record of discovery, not a timestamp of entry.

3.5 Pathways Create Geography

Introductions follow physical pathways, and different pathways leave different geographical and taxonomic signatures. In the Mediterranean, the Suez Canal, commercial shipping and aquaculture have been especially important, but they do not move the same organisms to the same places in the same way.

Katsanevakis et al. (2014) analysed version 3.2 of the European Alien Species Information Network catalogue, which contained 986 marine non-indigenous species in January 2014. One pathway was assigned to 799 species, more than one to 114, and the pathway remained unknown for 73. Under the higher-certainty attributions used in the analysis, 420 taxa were associated with the Suez Canal, 308 with shipping and 64 with aquaculture. These figures describe the inventory and attribution evidence available at that date, including uncertainty and multiple assignments. They are not fixed proportions of future introductions.

The Suez Canal connects previously separated biogeographical provinces. Organisms crossing into the Levantine basin may subsequently disperse through currents, movement or successive population expansion. Shipping operates differently: ballast water, sea chests and hull fouling can move organisms between distant ports and bypass an expected geographical progression. Aquaculture can introduce cultured organisms and associated biota near production and transfer sites. These pathways select different life histories and operate through different transport networks.

The updated Aegean synthesis reflects that variation. Secondary dispersal of Lessepsian species from the Levant and transport associated with shipping made broadly similar contributions across the inventory as a whole, while the non-indigenous fish inventory was dominated by species of Lessepsian origin (Zenetos et al., 2025). The prominence of one pathway for fishes does not determine the origin of molluscs, crustaceans, macroalgae or fouling organisms. Nor does it show that each species has one known route.

Pathway attribution is an inference supported by distribution, chronology, life history, transport opportunity and, sometimes, genetic evidence. A harbour record may be consistent with shipping without identifying a particular vessel. Indo-Pacific origin may make Suez passage plausible without excluding transport by ship. Appropriate attribution is therefore taxon-specific and expressed with uncertainty.

This distinction matters for management. A canal corridor, ballast discharge, hull fouling and aquaculture transfer require different interventions. A narrative that reduces every arrival to tropical species moving north and west obscures both causal geography and prevention.

3.6 Warming Filters; It Does Not Transport

Once pathways and thermal regime are separated, their interaction becomes clearer. Transport determines whether propagules reach a region or site. Environmental and biological filters influence whether they survive, reproduce, establish and spread. Temperature is one such filter, often an important one for warm-affinity organisms, but it is not the only one.

Warming can increase thermal suitability by reducing exposure to temperatures below an organism’s tolerance, extending periods favourable to growth or reproduction, or making formerly marginal habitats more permissive. The advantage depends on species, life stage and local environment, and it also depends on propagule supply (Raitsos et al., 2010; Giakoumi, 2014). A species cannot establish on a thermally suitable coast if it never reaches it; repeated introduction can fail where temperature, salinity, habitat or biotic conditions remain unsuitable.

Raitsos et al. (2010) examined records of 149 tropical non-indigenous taxa from 1924 to 2007 and identified an acceleration in recorded entries after a thermal shift around 1998, coincident with warmer

eastern Mediterranean conditions. The association is compatible with thermal filtering. It does not show that temperature alone caused every recorded appearance, separate biological arrival from detection effort or provide a contemporary establishment rate for the Aegean.

D'Amen et al. (2022) tested thermal matching across occurrence records for 22 Lessepsian fishes over six decades. Temperature match was associated with faster spread and became more common for later arrivals, yet several species, especially at leading edges, occurred beyond the temperature conditions represented in their native ranges. Thermal compatibility can facilitate spread; it is not a sufficient explanation of observed distribution.

The receiving ecosystem adds further filters. Substrate, depth, hydrodynamics and food availability determine whether a site supplies usable habitat. Resident predators, competitors, parasites and mutualists can suppress or facilitate establishment. Fishing may alter native predators, competitors and size structure; nutrient enrichment, pollution, anchoring and coastal construction may change habitat and resources. These pressures help explain why the same species remains scarce in one locality, becomes abundant in another and produces measurable effects only under certain conditions (Tsagarakis et al., 2022; Tsirintanis et al., 2022, 2023).

Warming must therefore be assigned a precise causal role. It can alter probabilities of survival, establishment and spread and change the balance between warm- and cool-affinity organisms. It cannot explain the transport event by which an organism arrived. Nor does thermal suitability prove establishment, which requires evidence of reproduction, recruitment and persistence.

The conditional sequence is:

> pathway and propagule supply → environmental and biological filtering → possible establishment → possible spread → separately tested impact

Repeated introduction may reinforce small populations, and ecosystem change may modify the filters themselves. The sequence is therefore a simplification, but a useful one. It prevents one causal category from doing the work of all the others.

3.7 From Presence to Uneven Impact

The consequences of non-indigenous species vary in magnitude, mechanism and sign. Some alter habitat-forming communities or trophic interactions; some damage fishing gear, reduce catches or threaten human health; some enter markets and acquire value; many remain insufficiently studied. The relevant question is not whether non-indigenous species are collectively beneficial or harmful. It is which organism affects which response, under what conditions, at what scale and with what evidence.

Regional impact mapping can identify priorities but should not be treated as field measurement. The CIMPAL analysis combined species distributions, habitat information and documented impact scores to estimate cumulative negative pressure across the Aegean (Tsirintanis et al., 2023). Higher modelled pressures occurred more frequently in the South Aegean and on shallow hard substrata. The pattern identifies species and habitats warranting attention. It is not an in situ measurement of damage in every mapped cell or a comprehensive ecological-status assessment for Paros.

Different dimensions of impact also require different designs. An experiment may show that herbivores can reduce erect algal biomass under specified conditions while leaving economic consequences unmeasured. Interviews may document gear damage and perceived loss without determining effects on prey populations. Tissue analysis may establish a public-health hazard without describing ecosystem function. These are not weaker forms of one question; they are different questions.

Positive and negative consequences may coexist across groups. A non-indigenous fish may have landing value and also damage gear. Market value does not cancel ecological effect, and ecological concern does not erase income. This distinction becomes central in the comparison between rabbitfish and silver-cheeked toadfish. The first offers comparatively strong evidence for a grazing mechanism in parts of the eastern Mediterranean. The second presents a different combination of trophic ecology, toxicity and fishery damage. Treating both simply as “invasive fish” would conceal the mechanisms that make them informative.

3.8 Paros–Antiparos: A Local Test, Not a Local Verdict

The local record can now be placed more precisely along the sequence from arrival to impact. In July 2011, *Siganus luridus* occurred at all 14 shallow stations and was described as the dominant herbivorous fish; in August 2020, two *Urocaridella pulchella*, including an ovigerous female, were observed in Pantieronisi cave (Katsanevakis, 2011; Digenis et al., 2021). The first record establishes widespread occurrence within the sampled shallows by that date. The second establishes presence and reproductive condition at one cave visit. Neither identifies the exact route or date of arrival, subsequent abundance change, successful recruitment or ecological effect.

Regional pathway histories remain taxon-specific. Some fishes have well-supported Lessepsian histories; other organisms may be associated with shipping, aquaculture or more than one route. Secondary spread within the Aegean can further separate the place of initial Mediterranean introduction from the route by which an organism reached a particular island.

Regional thermal evidence supports a testable local hypothesis: warming may have increased thermal suitability for some warm-affinity non-indigenous species around Paros and Antiparos. No repeated local inventory linked to habitat-specific temperatures currently estimates establishment, spread or

abundance change as a function of warming. The hypothesis is biologically plausible and regionally supported; its local effect size remains unknown.

The distinctions are therefore substantive, not semantic. Regional warming is not local habitat temperature; a record is not an arrival date; presence is not establishment; establishment is not spread; and spread is not measured impact. The local observations establish historical presence and identify high-value questions. They do not supply a present inventory, a trend, a pathway history for every taxon or a cumulative impact estimate.

Siganus luridus provides the strongest bridge to functional analysis. Its occurrence at every station in 2011, its herbivorous role and experimental and comparative evidence elsewhere in the eastern Mediterranean make grazing a plausible mechanism for detailed examination. They do not show that rabbitfish caused the barrens recorded around Paros or that warming alone produced its local distribution. Chapter 4 therefore asks a narrower question: under what conditions can changing herbivory transform a rocky reef, and how much of that mechanism can legitimately be transferred to these islands?

Chapter 4 — When Grazing Changes

The first functional case is grazing. *Siganus luridus* occurred at all 14 shallow stations surveyed around Paros and Antiparos in July 2011, and the survey described extensive barren rocky areas (Katsanevakis, 2011). This conjunction is ecologically important, but it is not a causal test. The survey measured presence, not rabbitfish biomass, bite rates, sea-urchin density, algal production or change through time.

A *barren* is therefore treated here as a benthic state rather than a diagnosis. It describes rock with very little erect algal cover, often dominated by encrusting organisms or a thin algal layer. The same appearance can arise through different sequences: grazing may remove vegetation; heat or physical disturbance may first eliminate a canopy and grazing may then prevent its return; or recruitment, nutrients, sediment and exposure may limit recovery. Creation and maintenance are distinct causal questions.

This distinction makes grazing an unusually useful case. Unlike presence alone, feeding can be observed, consumers can be excluded and benthic response can be measured. Yet grazing pressure belongs to an assemblage, not automatically to one species. It depends on grazer identity, abundance, body size, diet, movement, grouping behaviour and habitat, as well as the ability of algae to grow and recruit under local conditions.

4.1 From Local Co-occurrence to Experimental Mechanism

The 2011 Paros–Antiparos assessment establishes a historical local anchor. *S. luridus* was widespread across the sampled shallow habitats and was described as the dominant herbivorous fish observed (Katsanevakis, 2011). It does not establish that rabbitfish created the barrens, that their abundance remains unchanged, or that the same relationship applies across every depth, habitat and season.

The strongest experimental bridge comes from already barren reefs near Kaş, Fethiye and Bodrum in south-western Turkey. Sala et al. (2011) excluded larger grazing fishes and compared the benthic response with uncaged plots. Rabbitfish represented 83–95% of recorded herbivorous-fish biomass at the sites, while sea urchins were not recorded in the study transects and quadrats. Algal biomass remained low under continuing fish access but recovered inside the exclusions.

The experiment demonstrates that larger grazing fishes maintained low algal biomass under those local conditions. It was not a selective rabbitfish removal. Juvenile *Siganus* later entered cages after mass recruitment and rapidly removed much of the recovered vegetation, strengthening species-level plausibility without turning the assemblage-level manipulation into species-specific proof. The design

also lacked a structure-only cage control, and cage loss shortened parts of the time series. These qualifications constrain the wording, not the existence of the large treatment contrast.

Because the experiment began on established barrens, it identifies maintenance more securely than origin. It shows that continuing fish grazing can prevent algal recovery once a low-vegetation state exists. It does not reconstruct what first removed the canopy. Applied to Paros, the experiment supplies a mechanism and a design, not a local effect size or causal history.

4.2 Grazer Identity, Complementarity and Behaviour

Regional comparisons show why herbivore biomass alone is insufficient. Vergés et al. (2014) compared 54 sites in nine regions of Greece and Turkey. Regions with abundant rabbitfish had 65% lower canopy-algal abundance, approximately 60% less total benthic biomass and 40% lower species richness than regions where rabbitfish were absent or scarce. These were synchronous regional contrasts, not experimental coefficients. Geography, temperature, habitat, invasion history and fishing also varied, so none of the three percentages can be transferred numerically to Paros.

The feeding assays in the same study were informative because herbivores divided resources. *Siganus luridus* browsed adult brown algae, *S. rivulatus* concentrated on the epilithic algal matrix, and native herbivores also used parts of that matrix, seagrass or adult algae. Total consumption was not greater at the rabbitfish site. The result instead supports functional complementarity: different consumers can remove adult tissue and crop recruits at successive stages of algal recovery. It does not show that all mixed grazer assemblages cross a threshold into barrens.

Behaviour may alter the concentration of this pressure. At seven Cretan locations selected for high herbivore activity, Minguito-Frutos et al. (2025) observed 250 shoals and followed 294 focal fishes. Rabbitfish bite rates increased with shoal size in both monospecific and mixed groups, giving range-extending rabbitfish access to larger effective foraging groups. The study was observational and did not measure a benthic phase shift. It identifies a plausible behavioural mechanism, not proof that mixed shoaling created canopy loss.

The relevant local question is consequently more demanding than a rabbitfish count. It asks which species and sizes feed, in what groups, on which benthic components, at what rate and in which seasons. Presence and biomass are necessary measurements, but they do not by themselves reveal function.

4.3 The Cycladic Gradient and Its Limits

The closest geographical comparison is Giakoumi's (2014) survey of 180 rocky sites around 18 Cycladic islands in 2008. The study recorded 337 *S. luridus*, approximately 17% of herbivorous-fish abundance,

with a strong south-east to north-west gradient. Rabbitfish abundance was positively associated with March sea-surface temperature, used as a proxy for winter minimum, and negatively associated with the combined cover of erect and canopy-forming macroalgae.

The pattern is consistent with thermal filtering and grazing impact, but neither was manipulated. A single-period association cannot show that warming caused an increase through time, and the negative algal relationship cannot distinguish consumption from habitat selection or an unmeasured common driver. The relationship concerned a functional grouping of erect and canopy algae; *Cystoseira* considered alone did not show the same significant association.

Wider Cycladic surveys reinforce this heterogeneity. Across 181 shallow rocky sites around 25 islands, turf was widespread, canopy algae were more frequent in northern islands, fish biomass varied strongly and sea-urchin biomass was positively associated with barren cover (Giakoumi et al., 2012). Potential apex predators were scarce, yet the expected predator–urchin cascade did not organise the regional pattern clearly. A related survey of 233 sites found strong effects of substrate on fish assemblages, with lower abundance and biomass on sand and higher values on hard bottom (Giakoumi and Kokkoris, 2013). Comparisons around Paros must therefore match habitat at minimum; membership in the Cyclades is not itself a measurement.

4.4 Rabbitfish Are Not the Only Grazers

Experiments in the northern Aegean show that native sea urchins can occupy the same functional role. At three shallow Lesvos reefs, Tsirintanis et al. (2018) compared full exclusions, open-top treatments that excluded urchins while permitting fish access, and open plots. Algal growth increased when urchins were excluded, while full and open-top exclusions did not differ significantly in total algal growth. Under those conditions, native urchins were the dominant measured grazers and no additional effect of excluding large herbivorous fishes was isolated.

This does not contradict the Turkish fish-exclusion result. It demonstrates contingency: the consumer maintaining low algal cover differed between study systems. A 2020–2022 survey of 17 sites from Lesvos to Israel reached a compatible conclusion by a different route. Canopy occurrence was negatively associated with alien-herbivore biomass, sea-urchin abundance and depth, while urchins were absent or scarce at many southern sites where canopy loss was extensive (Nikolaou et al., 2023). The study was observational, not fully synchronous among regions, and used some protocol differences. It supports multiple grazing pathways, not one basin-wide attribution.

Urchin effects are themselves sensitive to climate and food-web context. On the Israeli coast, contemporary rarity of *Paracentrotus lividus* coincided with strong mortality under warm laboratory treatments; in the experiment, mortality rose sharply above approximately 30.5°C (Yeruham et al.,

2015). That response belongs to the tested population and conditions. It is neither a universal Mediterranean threshold nor a temperature estimate for Paros.

Nor does reducing a grazer guarantee restoration of the former habitat. Large-scale urchin culling in Apulia reduced bare substrate and released mainly turf-forming algae, but did not recreate a mature canopy forest or the original community (Guarnieri et al., 2020). Grazing was therefore a barrier to recovery, but not necessarily the only one. Propagule limitation, sediment, water quality, thermal stress and physical disturbance can remain decisive after grazer pressure falls.

Fishing may alter predators, herbivorous fishes and harvested urchins, but the Cycladic evidence does not establish a universal fishing-driven trophic cascade. Coastal construction, anchoring, sedimentation and pollution can also initiate canopy loss directly. A sequential history is plausible: disturbance removes vegetation, grazing prevents recovery and warming changes the performance of both consumers and producers. A later snapshot cannot identify that sequence without additional evidence.

4.5 Herbivory Redistributed

Tropicalisation can redistribute a function even where no temporal phase shift has been measured. Across 20 Mediterranean sites, Santana-Garcon et al. (2023) combined 755 feeding observations with herbivore and resource data. Their composite proxy of consumption pressure was concentrated more strongly in seagrass meadows in the west and on rocky-reef macroalgae in the east. Because the comparison was cross-sectional and combined differences in communities, food choice, temperature and habitat, it does not show that warming alone produced the geographical contrast.

At six sites around Lipsi, Wong et al. (2026) found that the two alien rabbitfishes represented about 35% of recorded herbivorous fishes. Feeding by native *Sparisoma cretense* was negatively correlated with the pooled activity of the two rabbitfish species, but not significantly with either alien species analysed separately. Repeated transects and visits were treated as independent observations, and the study covered one spring. The pooled association motivates hypotheses of competition, resource depletion or spatial avoidance; it does not demonstrate displacement in Lipsi, the Aegean or Paros.

The emerging change is thus not simple replacement. Rabbitfish may add feeding modes, join native shoals, overlap with resident herbivores or concentrate pressure in different habitats. Native consumers may persist while altering their distribution or behaviour. Ecological reorganisation lies in these changed relations and functions, not merely in the addition of names to a species list.

4.6 The Four Local Reef Stations

The most recent local macroalgal evidence in the verified corpus comes from four rocky stations at Ebriokastro, Santa Maria, Panteronisi and Petalida, sampled in 2016 or 2020 (Savin et al., 2023). Mean

station-level values from a vegetation-restricted application of reef-EBQI fell in the category “Bad”. These are direct observations of macroalgal ecological status under a specified method and at specified places.

They are not a repeated survey of the 2011 stations, an integrated assessment of whole-reef condition or an island-wide diagnosis. The protocols, spatial footprints and purposes differ, and the exact sampling year is not resolved identically for every station in the accessible synthesis. The values cannot be joined to the 2011 rapid assessment to manufacture a trend, nor can the regional summary and its four local records be counted as independent replications.

The index also does not identify cause. At Panteronisi, two macroalgal methods did not assign identical categories, illustrating how method, depth and the ecological component assessed affect the result. No regional percentage or exclusion effect can decompose a Parian index value. The external studies show what mechanisms and measurements deserve attention; they do not allocate the local result among rabbitfish, urchins, heat, fishing, water quality and direct habitat disturbance.

4.7 Paros–Antiparos: A Testable Hypothesis

The evidence supports a bounded synthesis. *S. luridus* occurred at all 14 shallow stations surveyed in July 2011 and was described as the dominant herbivorous fish observed. Four later rocky-reef stations received mean vegetation-restricted reef-EBQI classifications of “Bad”. Experiments elsewhere demonstrate that excluding fishes or urchins can release algal growth under particular conditions, while regional comparisons associate both groups with reduced erect or canopy algae and reveal strong geographical and habitat dependence.

These propositions cannot be collapsed into the claim that rabbitfish caused degradation of Paros reefs. The local observations are not synchronised, the experiments manipulate different grazer assemblages and the regional studies do not isolate all co-varying drivers.

A decisive local test would align rabbitfish, native herbivores and urchins with grazing, algal structure, recruitment, temperature, habitat and competing pressures. Repeating the 2011 stations would update distribution, while resampling the four reef sites would test persistence; neither would establish causality alone. Fish and urchin exclusions could test maintenance mechanisms, but recovery of turf would not be equated with restoration of canopy habitat, and historical evidence would still be required to investigate origin.

The hypothesis is therefore strong enough to test and too incomplete to declare. Paros–Antiparos has a historical record of widespread rabbitfish and later evidence of poor macroalgal status at four specified stations. Altered grazing is a credible explanation, but its present contribution, trajectory and rank among competing pressures remain unknown.

Chapter 5 — Silver-Cheeked Toadfish: A Different Kind of Impact

The silver-cheeked toadfish, *Lagocephalus sceleratus*, requires a different evidential map. Its documented consequences extend across trophic behaviour, habitat use, toxicity, damaged fishing gear, lost catch and public intervention. These domains are connected, but they do not share a single burden of proof. Stomach contents establish consumption, not a decline in prey populations. A tissue assay establishes hazard, not abundance. A damaged net records an operational impact, not an island-wide loss. A payment per kilogram creates an incentive, not evidence of population control.

The distinction is particularly important around Paros and Antiparos. The species had been recorded off the islands but was not encountered in the 14 shallow snorkelling stations surveyed in 2011 (Katsanevakis, 2011). That protocol covered visible macroscopic biota from zero to ten metres during a short summer period. Non-detection is not absence from deeper grounds or other habitats, just as regional prominence cannot be converted into a present local population estimate.

5.1 A High-Trophic-Level Consumer

Diet studies establish that *L. sceleratus* is integrated into eastern Mediterranean food webs. Kalogirou (2013) examined 290 individuals collected seasonally from sandy habitats and *Posidonia oceanica* meadows around Rhodes at depths of five to 35 metres. Gomes et al. (2025) analysed 236 individuals collected around Crete between 2017 and 2022 at depths of 1.5 to 60 metres. In non-empty gastrointestinal tracts, the later study identified 38 fish and invertebrate species; fish were the principal prey category, followed by crustaceans and molluscs, and the estimated trophic level was 4.13.

These results support the description of a high-trophic-level consumer in the sampled populations. They do not support calling the species the dominant new predator of Paros. Dominance requires local abundance or biomass, consumption rates and comparison with other predators. Diet also varied with size, depth, season and region. A stomach records a limited interval and is filtered by prey availability, predator size, capture method, digestion and taxonomic resolution.

The Rhodes study adds demographic structure. Juveniles were associated more strongly with sandy habitats, while larger reproductive individuals occurred principally in seagrass meadows; the combined-sex estimate of length at 50% maturity was 36 centimetres in that study (Kalogirou, 2013). This does not establish Parian *Posidonia* as a breeding habitat. It shows why shallow visual surveys, net catches and sampling along seagrass edges may observe different segments of the same population.

Any local abundance index must consequently be stratified by habitat, depth, season and size. Fisheries-dependent observations need gear, location and effort; fisheries-independent sampling needs searched

area or time. Without those denominators, rising encounters can reflect more fish, more effort in susceptible habitats, improved recognition, changed gear or several of these processes together.

5.2 A Stomach Is Not a Food Web

Predation has three evidential levels. Consumption is shown when prey is identified in a stomach or molecular sample. Predation pressure requires consumption, predator abundance, feeding rate and prey availability. Population or community impact requires evidence that removal changes prey biomass, demography, recruitment or behaviour relative to a credible counterfactual.

The available studies establish the first level for many prey categories and inform the second only indirectly. They did not measure independent prey availability in a form that would estimate local selection and removal, nor did they compare prey trajectories under different toadfish pressure. Commercially valued prey in a stomach proves that an individual was eaten. It does not show that the predator caused a stock decline, that the individual would otherwise have entered a fishery, or that its economic loss equals market price.

A trophic-impact programme would combine local stomach contents or metabarcoding, stable isotopes, prey surveys, predator abundance and size, and repeated prey observations. Bioenergetic or food-web models could then scale individual diets to flows, but their outputs would remain conditional on assumptions and calibration. Until such evidence exists, the locally defensible proposition is trophic integration, not demonstrated population impact.

This is the central contrast with Chapter 4. Grazer exclusions have directly linked consumer access to algal recovery in defined settings. For *L. sceleratus*, the evidence more securely establishes what is eaten than what changes because it is eaten.

5.3 Toxicity Changes the Risk Domain

Tetrodotoxin creates a direct human hazard. Anastasiou et al. (2023) analysed 145 tissue samples from 37 *L. sceleratus* collected around Rhodes in May and June 2021. Tetrodotoxin and its analogues were detected in liver, gonad, muscle and skin. Liver and gonads were the most toxic tissues, and 78% of muscle samples exceeded the Japanese toxicity threshold used by the study.

This is a direct laboratory result. It confirms that edible-looking muscle cannot be presumed safe and that toxicity was not confined to one organ in the sampled fish. The percentage cannot be extended to every Aegean population or season. Some analogues were assessed semi-quantitatively because certified standards were unavailable, and the Japanese comparison threshold is not a European authorization to consume material below it.

Hazard is not the same as realized exposure. Public-health risk also depends on recognition, entry into food channels, preparation, mislabelling, surveillance and communication. Nevertheless, the species cannot be treated as an ordinary candidate for seafood-market development. European hygiene rules prohibit fishery products derived from poisonous Tetraodontidae from being placed on the market (European Parliament and Council, 2004). A removal operation must therefore include secure handling, storage, transport and disposal. Kilograms removed are both a management output and a hazardous-material stream.

5.4 When the Fish Meets the Net

The most direct fishery evidence concerns encounters with gear. Christidis et al. (2024) interviewed 141 professional small-scale fishers across 45 Greek ports and placed observers on 208 fishing trips around Crete. *L. sceleratus* occurred in 42 trips; 86 individuals weighing 123 kilograms represented 3.8% of recorded catch. Gear or catch damage was observed in 46 trips. These events demonstrate operational harm in the sampled fishery rather than perception alone.

The observations do not establish a Greek average. Encounter probability varied with geography, depth, sea-surface temperature and gear. Annual costs estimated from interviews were €6,315 ± €2,620 per vessel in the studied Cretan areas and €258 ± €120 in the Ionian area (mean ± SE). The roughly twenty-five-fold contrast is evidence of geographical contingency. The estimates combine reported quantities with fisher-declared unit values and must not be multiplied across the Parian or national fleet.

Adaptation can obscure the burden. Fishers may change grounds, gear, soak time or targets after damage. Recorded repair costs may fall while fuel, labour, risk or forgone catch rises. Conversely, learning can reduce losses without any decline in fish abundance. A local series therefore needs standardised effort and behaviour as well as incidents.

Evidence from eastern Cyprus illustrates the same problem at fleet scale. Six non-indigenous taxa represented 29% of landed weight and 28% of declared value in the studied areas during 2017–2019 (Kleitou et al., 2022). Self-reported losses attributed jointly to *L. sceleratus* and *Torquigener flavimaculosus* were extrapolated to €325,535 per year, equivalent to 56% of declared landing value in 2019. These are case-study estimates based partly on interview reporting, not audited species-specific losses or values transferable to Paros.

The Parian evidence remains narrower. Moutopoulos et al. (2025) surveyed 70 professional small-scale fishers across seven ports, including Paros, but did not tabulate the number at each port. Percentage increments are consistent with 16 Parian respondents, although that reconstruction is not a reported sample size. The explicit high gear-damage percentage for Paros and the Argolic Gulf concerned *S. luridus*. The 72.3% damage figure for *L. sceleratus* was pooled across ports and was highest in Amorgos

and the Argolic Gulf. The study confirms local fisher knowledge and reported interactions with non-indigenous species; it does not provide Parian toadfish CPUE, annual cost or species-specific attribution of all damage.

Fisher testimony is not inferior evidence. It answers questions about experience, rare events, adaptation and possible hotspots that short surveys may miss. It becomes a comparable time series only when recall period, denominator, species identification and cost categories are standardised and, where feasible, triangulated with logbooks, invoices, landings and observers.

5.5 €5.33 per Kilogram Is a Programme Design

On 29 June 2026, the Greek Ministry of Rural Development and Food issued a call for a joint pilot proposal from Crete and the South Aegean concerning targeted fishing of *L. sceleratus*. The call specified up to €1.5 million in public expenditure, possible net remuneration of up to €5.33 per kilogram, and provisions for collection, storage, weighing, management and scientific monitoring. The regions were invited to submit a joint proposal by 30 September 2026 (ΥΠΑΑΤ, 2026).

At the evidence cut-off of 28 July 2026, the verified record established a call and invited proposal. It did not establish selection, funding agreement, operational start, verified removals, payments, population response, ecological recovery or reduced fishery damage. These are separate stages and require separate records.

The programme also contains at least two objectives. Compensation may support fishers who handle a damaging, non-marketable species. Control may seek to reduce abundance or ecological pressure. A scheme can transfer income without suppressing a population, remove fish without covering losses fairly, or achieve both. Kilograms landed cannot distinguish among these outcomes unless linked to standardised effort, size structure and an independent population index.

The eastern Cypriot case provides a useful accounting warning. Using the official 2019 value of pooled *Lagocephalus* landings, €73,550 at €3 per kilogram, as the numerator, Kleitou et al. (2022) derived a compensation-equivalent ratio of about 23% relative to the extrapolated €325,535 in self-reported damage from two pufferfish species. The ratio was not an audit of individual reimbursement. The study reported that fishers adapted summer targeting to benefit from the subsidy, but it did not isolate the subsidy's causal effect on effort or abundance and did not demonstrate population suppression.

A credible evaluation should begin before fishing. Effort, CPUE, biomass, size, sex and maturity require spatially explicit comparison areas or phased implementation. Removal mass should be linked to vessel effort. Fishery outcomes should include gear damage, lost catch, operating time and net income. Ecological outcomes should correspond to plausible pathways, while chain-of-custody records should

document safe treatment of toxic material. The unit price is an incentive within this programme theory, not an ecological coefficient.

5.6 Paros–Antiparos: What Would Decide

The evidence supports an asymmetric conclusion. Trophic integration is well documented regionally, serious tissue toxicity has been measured in the south-eastern Aegean, and direct fishery damage has been observed in selected Greek waters. What is absent is a representative contemporary estimate of local abundance, a Parian diet study, a demonstrated prey-population effect, a standardised annual island cost or an evaluated removal outcome.

A local assessment would require habitat- and effort-specific abundance and demographic observations, paired with a stable vessel panel recording encounter, damage, lost catch, cost and adaptation. Toxicological work would remain a hazard study, not a route to consumption, and operational safety would remain mandatory. If the South Aegean programme proceeds, abundance, size structure, gear damage and economic outcomes must be compared against pre-removal baselines and analysed separately from kilograms delivered. Migration, recruitment and redistributed fishing effort remain alternative explanations for change.

Rabbitfish and toadfish therefore represent different kinds of impact. Grazing has the stronger experimental ecological mechanism; *L. sceleratus* has the stronger direct evidence of toxicological and operational harm. Neither case can be reduced to presence, and neither can borrow the strongest evidence of the other.

Chapter 6 — Fishing as a Co-Driver

Fishing is both a receiver and a producer of ecological change. An unfamiliar species may damage gear or alter catch, but fishing also removes organisms selectively, changes the sizes and functions that remain, redistributes effort among habitats and modifies the community in which warming and non-indigenous species operate. Climate change does not encounter a pristine Aegean food web. It acts on communities that may already carry the imprint of decades of incompletely recorded extraction.

Calling fishing a co-driver does not assign it a fixed share of every change. Temperature, production, recruitment, predation, regulation, technology, markets and reporting can affect the same biological or landing series. Their effects can reinforce or oppose one another and can act at different life stages. The three-axis frame of this essay, climate, non-indigenous species and fishing pressure, denotes interaction and co-occurrence, not equal weights or a demonstrated local equation.

Body size exposes the difficulty. “Fish are becoming smaller” can mean slower individual growth, earlier maturation, fewer old individuals, a smaller observed maximum, a community composed of smaller species, or a catch weighted toward lower trophic levels. These measurements may move together without sharing a cause. No local Paros–Antiparos series currently establishes any one of them as a trend.

6.1 Selective Removal and Coupled Dynamics

Mesh and hook size, gear, target, habitat, depth, season and market value influence what is encountered and retained. Fishing mortality may concentrate on large and old individuals, a reproductive segment or a functional group. Discards and unreported removals add selection that declared landings cannot show. A population can therefore shift toward smaller size classes even if the growth of each survivor remains unchanged.

Aegean ecosystem models illustrate why one-pressure explanations are insufficient. Tsagarakis et al. (2022) represented the northern Aegean with 40 functional groups, fitted the model retrospectively for 1993–2020 and simulated scenarios to 2050. Historical fit improved when trophic interactions, fishing, sea-surface temperature and primary production were considered together. Lower fishing effort generally increased simulated biomass for many groups but reduced catch, while environmental responses differed among groups.

Keramidas et al. (2024) developed an Aegean-wide model with 44 functional groups and four fleets, calibrated for 2006–2021 and simulated to 2050. Lower effort again tended to raise biomass while reducing short-term catch, and combined fishing and warming scenarios produced heterogeneous,

nonlinear responses. Non-indigenous species were omitted because official catch series were inadequate, a limitation directly relevant to this essay.

These are structured scenarios, not controlled removals or forecasts for the Cyclades. Their results depend on diet matrices, grouping, thermal-response assumptions and incomplete time series. Their contribution is conceptual: a historically fitted ecosystem could not be represented adequately by one pressure, and the effect of effort differed among functional groups and between the outcomes of biomass and catch.

6.2 Four Meanings of “Smaller”

An individual trajectory concerns length or mass at age, growth, maturation and asymptotic size. Demonstrating change requires comparable biological observations with age, sex, maturity, food and thermal context. A small adult may have grown slowly, matured early, experienced limited food or survived a different mortality regime.

A population size structure describes abundance across size classes. It can change through growth, recruitment, selective mortality, cohort strength or uneven sampling. A strong juvenile year class can shift a spectrum toward smaller fish without any decline in adult growth.

Maximum observed length is a third quantity. It describes the upper tail of a sampled distribution and is sensitive to gear, habitat, effort and the chance of encountering rare old individuals. It is not mean adult length or a full size spectrum.

Catch composition is a fourth. Catch-weighted mean trophic level can fall because low-trophic-level species occupy a larger share of landings even when size within each species is unchanged. Landings also omit discards and may change with prices, regulation or reporting. None of these four measures can substitute for another.

6.3 The Strait of Sicily Test

Gjoni et al. (2026) analysed MEDITS observations from GSA 16 in the Strait of Sicily for 2000–2023. The accepted manuscript reports 1,090 standardised trawl hauls and 211,070 individual records across nine commercially important fishes, crustaceans and cephalopods. Bayesian models related size spectra to temperature and trawling-effort layers.

For European hake, striped red mullet and red mullet, warmer and more intensely trawled locations were associated with distributions containing a larger proportion of small individuals. The crustaceans and cephalopods did not reproduce a single fish-like response. The evidence therefore supports a

restricted proposition: temperature and fishing pressure carried joint information about the size structure of the three studied fishes, while responses remained taxon-specific.

Fishery-independent sampling reduces distortion from market retention and target choice, but the study was not an experiment. Hauls were not randomly assigned to treatments, and habitat, depth, production and recruitment history may contribute to the fitted associations. The biological series, climatological temperature layer and 2012–2020 fishing-effort layer were aligned spatially at a coarse scale rather than as a complete annual exposure history.

The numerical record also requires care. An earlier preprint reported 26,856 observations; the accepted manuscript reports 211,070 and is the operative source. At the evidence cut-off of 28 July 2026, the publisher still identified it as an unedited accepted manuscript. The final version should be checked before public release.

Nothing in the design supplies a Cycladic effect size. Its transferable result is a hypothesis and method: standardised size spectra may reveal a joint fishing–temperature signal. Direction and magnitude must be measured for each local species and system.

6.4 Driver Importance Is Stock-Specific

Tu et al. (2018) analysed more than 20 years of annual observations for each of 28 exploited fish stocks from the western United States, Alaska and the North Sea. Fishing explained an average of 10.9% of variation in size-class composition and, across the assembled stocks, more than temperature or the interaction term. Yet a significant fishing association appeared in only 12 stocks and a temperature association in seven. Even the best combined model reached an adjusted R^2 of 44%.

The average cannot be used to rank drivers in Paros. Most variation remained outside the fitted terms, and the balance differed among stocks. Linear models may also miss thresholds, lags and recruitment pulses. The appropriate conclusion is structural: fishing and temperature can both affect size composition, their apparent importance is population-specific and a model containing both can still leave most variation unexplained.

The Aegean ecosystem scenarios agree at the level of heterogeneity, not at the level of a local size effect. Functional-group biomass in Ecosim is not a length-frequency series for an exploited stock.

6.5 A Spatial Gradient Is Not a Forecast

van Rijn et al. (2017) synthesized local maximum lengths for 74 species across the Mediterranean, Black Sea and adjacent Atlantic. Across the spatial gradient, a 1°C difference was associated on average with

an approximately 5% lower maximum length. Responses varied among species, with activity, common length and minimum depth helping explain some of the difference.

The 5% figure is not an annual rate, a future projection or a coefficient for every species. The synthesis combined locations, dates and sampling methods. Warmer and cooler places differ in more than temperature, and maximum length depends partly on the probability of sampling rare large individuals. Space-for-time substitution may also incorporate long-term acclimatization, adaptation, migration and historical fishing that need not unfold at the same rate during rapid local warming.

The defensible statement is therefore in the past tense and at the measured scale: warmer locations were associated on average with smaller recorded maximum length across the 74-species synthesis. It cannot become a forecast that Parian fish will shrink by 5% per additional degree.

6.6 No Universal Physiological Rule

Temperature changes feeding, maintenance, activity, growth, maturation and reproduction. The net response depends on thermal position, food, oxygen and life stage. Experiments reject a single universal pathway.

Person-Le Ruyet et al. (2004) reared 1,008 juvenile European sea bass for 84 days at six constant temperatures from 13 to 29°C under near-oxygen-saturated culture conditions. Growth increased through 25°C, while mass gain at 29°C was about 6% lower by day 84. The study demonstrates nonlinearity under controlled juvenile conditions, not a field threshold or final adult size for the Aegean.

In a tropical reef fish, higher food did not universally overcome thermal limitation. Munday et al. (2008) found declining growth across increasing temperatures, with the advantage of high ration greatly reduced at 31°C for juveniles and adults. The species and setting prevent transfer of a Mediterranean effect size, but the experiment demonstrates interaction among temperature, food and life stage.

Life-history allocation offers another route. Across six generations, zebrafish reared at 30°C grew faster early but matured earlier and at smaller size than fish at 26°C; baseline metabolic rates converged while reproductive allocation changed (Wootton et al., 2022). Smaller adults therefore need not imply chronically elevated basal metabolism.

Oxygen is important without acting as a master rule. *Galaxias maculatus* reared for a year at 20°C grew faster and matured earlier than fish at 15°C. Supplemental oxygen increased maximum oxygen uptake but not mean size at maturation or adult size, instead extending the reproductive window (Skeeles et al., 2023). The result tests one oxygen-limitation prediction in one species; it does not show that oxygen never constrains growth.

Warm-adapted populations add further complexity. Johansen et al. (2024) compared two fish species from the Persian/Arabian Gulf and Gulf of Oman. Maximum sizes recorded for Gulf fish were 14–40% smaller, yet their aerobic performance remained robust through species-specific metabolic and thermal adjustments. Small experimental samples and regional differences prevent causal attribution to temperature alone.

These studies define a decision tree rather than one law. Warming below an optimum can accelerate early growth; above it, growth can decline despite food; maturation and reproductive allocation can alter adult size; oxygen effects vary; and warm-adapted populations can maintain performance through different adjustments. Fishing adds selective mortality, a route absent from these laboratory treatments. Length alone cannot identify which mechanism operated.

6.7 What Aegean Catch Series Show

Touloumis et al. (2025) analysed official HELSTAT landings for 59 species or groups from 1982 to 2020. Catch-weighted mean trophic level declined from approximately 3.5 in the early 1980s to below 3.2 in 2020, about 0.05 trophic level per decade. The Fishing-in-Balance index rose until the mid-1990s and then fell to its lowest value in 2020.

The pattern is compatible with fishing down, but it is not a direct measure of fish length, biomass, fishing mortality or trophic cascade. Global trophic values, taxonomic aggregation and omission of discards, illegal catch, and recreational and subsistence fishing constrain interpretation. Small pelagics, more than 40% of landings in the study's accounting, were excluded from the principal mean-trophic-level calculation to prevent their variability from dominating the indicator.

A later reconstruction shows how strongly the observation system matters. Touloumis et al. (2026) reconstructed Greek, Aegean–Cretan and eastern Ionian catches for 1950–2022 using fleet-specific corrections, discard estimates and recreational-catch estimates. It retroactively included small coastal vessels below 20 horsepower, which older HELSTAT sampling had omitted.

In the only overlap year, 2016, all-vessel small-scale landings totalled 32,741.4 tonnes compared with 16,023.6 tonnes for the formerly covered segment; 51.06% came from vessels below the old threshold. The reconstruction estimated historical total catch underreporting above 25% and attributed the apparent post-2016 recovery in official series to expanded coverage. In the reconstructed series, catch peaked around 1994, followed by contraction in 1995–2007 and recession in 2008–2022 relative to the maximum.

This is a correction, not a census. The small-vessel adjustment is projected backward from one overlap year; discard ratios and recreational estimates rely on later observations and fixed assumptions; some aggregated groups remain unresolved; and illegal catch is absent. The reconstruction demonstrates that

an administrative change can create a phantom biological story. It does not establish stock collapse or local change around Paros.

The series also does not quantify removals by non-Greek fleets. Claims about a particular foreign fleet require consistent spatially resolved effort and, for ecological contribution, catch or validated removal estimates. Transboundary pressure remains a research question in this essay, not a result.

6.8 Paros–Antiparos: The Missing Denominator

The verified corpus contains no local time series that aligns fish lengths or size spectra around Paros–Antiparos with standardised fishing effort, CPUE and habitat-level temperature. This does not prove that no unpublished records exist. It means that the proposition that local fish have become smaller because of fishing and warming remains a hypothesis.

Historical experience can help identify practices, possible changes and shifting baselines, but it cannot reconstruct effort, legality or biomass removal without contemporaneous denominators. The author's observations are therefore treated in Chapter 8 as bounded testimony, not a quantitative correction or independent validation of the national reconstruction.

A local programme must first specify which meaning of "smaller" it tests. Fishery-independent length distributions, age and maturity observations and gear-specific catch and effort would distinguish altered growth, truncated population structure, maximum length and changing catch composition. Habitat-depth temperature, reporting coverage, recreational removals, discards and informal flows must remain explicit, separate layers.

Such a system could test independently whether fishing pressure is associated with smaller or younger population structure, temperature alters growth or maturation, catch composition changes without within-species shrinkage, and lower effort raises biomass while reducing short-term catch. Divergence among species or indicators would reveal different processes, not analytical failure.

Fishing is thus a co-driver because it selects organisms, responds to ecological change and is itself filtered by regulation, technology and markets. Measuring only what reaches the quay collapses those processes. The next chapter follows the argument across the quay, where biological change becomes unevenly distributed cost, risk, adaptation and value.

Chapter 7 — From Ecology to Human Consequences

Fishing changes marine populations through selective removal, while ecological reorganisation changes what fishers encounter, retain, avoid and sell. Crossing this boundary does not turn an ecological observation automatically into an economic loss. A damaged net, altered catch, toxic fish, new restaurant product and projected biomass change are different events, measured through different instruments and borne by different people.

The word *impact* can conceal this chain. A changed ecological function may occur where no person is materially exposed. A fisher may adapt before a loss appears in landings. A new market may recover part of a private loss while creating handling, inspection or administrative costs. A subsidy may improve a participant's income without producing a net social gain, and kilograms removed can increase without abundance falling.

Human consequences are therefore distributive as well as aggregate. The same ecological change can reduce one fleet's income, create turnover elsewhere, alter restaurant value, impose a health-protection cost on the state and leave habitat loss unpriced. Analysis must identify who gains or loses, over what period, under which rules and relative to what counterfactual.

For Paros and Antiparos, the verified evidence supports direct hazards and regional examples of fishery damage, but not a local balance sheet. Models help identify connections and trade-offs; they do not provide local forecasts. Precaution can justify monitoring, prevention and reversible protection before every loss is monetised. It does not justify presenting a hypothesis as an observed local cost or an intervention as successful before its outcome is measured.

7.1 Consequences Have Bearers

An ecological variable has no monetary sign by itself. A consequence begins when change intersects with exposure: a vessel fishes an affected ground, a consumer encounters a hazardous product, a restaurant depends on a supply, a diver values a habitat or an authority assumes responsibility for surveillance and control.

Every impact statement needs four coordinates: the bearer, the population and place, the period and the counterfactual. A repaired net has an identifiable event and owner. A claim that climate change reduced local fishery income additionally requires a baseline and a causal route that distinguishes recruitment, effort, fuel price, regulation and demand.

Benefits require the same discipline. A positive dockside price is not evidence of ecological benefit or net livelihood improvement. Additional searching, sorting, handling and learning may raise costs; a new

product may substitute for a more profitable native catch; and restaurants may capture value while producers bear ecological risk.

SEICAT offers one way to record changes in human activities without converting everything to money. Galanidi, Zenetos and Bacher (2018) applied the framework to seven priority non-indigenous marine fishes. *L. sceleratus* received the highest documented category among the examined taxa and the greatest number of impact records. Its maximum category, Moderate, rested on six health records, while documented effects on fishing and recreation were Minor. This is a maximum documented negative-impact category, not a frequency, average severity, net balance or Mediterranean bill. Positive effects were outside the method, and cultural evidence remained sparse.

Monetary valuation answers a different question. A repair invoice may establish one material loss without showing a large change in an activity, while abandonment of a fishing ground may be consequential without creating an invoice. Non-market values, including habitat integrity, cultural attachment and the option of passing a functioning ecosystem to future generations, may be collectively held. Their absence from a commercial ledger makes the ledger incomplete, not the values zero.

7.2 From Physical Damage to Economic Loss

Evidence can be ordered by inferential distance. Direct observation records a fish, damaged gear or measured toxin. Administrative and transaction records contain weight, declared value, compensation or disposal cost. Interviews add experience, adaptation and informal losses. Derived estimates combine quantities and unit values or scale them to a fleet. Models connect ecological and economic components under assumptions.

Christidis et al. (2024) demonstrate the distinction. Onboard observations established toadfish encounters and damage in sampled Cretan trips. Interviews then supported annual vessel-cost estimates for selected regions. The first is event-level evidence; the second is a case-study monetary estimate. Neither is a national total or Parian annual cost.

Kleitou et al. (2022) combine official landings, interviews, behavioural response and extrapolated self-reported losses in eastern Cyprus. Each result may be informative, but they are not one kind of “measured cost”. The compensation-equivalent ratio described in Chapter 5 is not an audited percentage of individual losses reimbursed.

Even a repair invoice is not automatically net loss. A private account may include material, paid repair, crew time, foregone fishing time, lost catch, extra fuel and altered risk, less salvage and costs avoided. Counting both full replacement and repair can double count; valuing forgone catch at gross sales and subtracting the same sales again as lost profit does so again. Profit requires costs, not only revenue.

The social account differs from the private one. A public payment can reduce a fisher's loss, but it transfers resources from a budget rather than erasing the damage. It may be justified for equity, participation or public-good reasons. In a net social account, the cheque is not counted both as a new benefit and as disappearance of the underlying loss. Administration, monitoring, tax financing and behavioural effects enter separately.

Kourantidou et al. (2021) further show that recorded Mediterranean costs are geographically, taxonomically and sectorally uneven. A database of documented and monetised costs is not a census of all ecological and social harm. Informal losses and places with weaker reporting are underrepresented. No recorded cost means no recorded cost, not no impact.

7.3 One Catch, Several Ledgers

A kilogram of fish may pass from vessel to wholesaler, distributor, shop or restaurant. Its mass is related across the chain, but its economic entries are not interchangeable. Landed value is first-sale price multiplied by quantity. Revenue, profit, household income, value added, employment and consumer value measure different things. Sales at successive stages cannot be added and called social benefit because the same product would be counted repeatedly.

Ofir et al. (2026) illustrate this distinction through an Israeli model coupling a dynamic food web to 11 seafood enterprises. The 2023 base-year account followed local catch through producers, distribution, retail and restaurants, while scenarios imposed warming and changes in non-indigenous biomass to mid-century.

Within the model, non-indigenous groups represented an estimated 34% of catch and 42% of profits along the chain, while native high-value groups remained disproportionately important downstream. Restaurants generated the largest modelled contribution to value added and employment. These outputs show that ecological composition need not map one-to-one onto profit or jobs.

They cannot be imported to the Cyclades. The value chain was semi-static, several per-tonne relationships were held fixed, public data beyond wholesale were limited and some retail and restaurant information required reconstruction. Demand, imports, substitution, fuel, technology and regulation were not fully dynamic. The exercise is a conditional ledger for one shelf, not a forecast of what a warmer Parian sea will be worth.

A Paros–Antiparos chain would need to trace direct sales, cooperatives, intermediaries, local households, hotels, restaurants and exports from the islands. Tourism may change prices and accepted species seasonally. Crew may live locally while ownership or downstream profit lies elsewhere. The purpose of the chain is to reveal distribution, not to manufacture a large aggregate from overlapping turnover.

7.4 Adaptation Is Not Benefit

Fishers change grounds, depth, season, mesh, hooks, soak time, target and trip length. They may learn to handle unfamiliar species, find buyers or leave an activity. These responses can reduce recorded damage while concealing the burden that caused them.

Avoiding a ground with frequent pufferfish damage may reduce repair bills but increase fuel, search time, weather exposure, crowding or forgone catch. Calling the fall in damaged nets an ecological improvement would mistake avoidance for removal of pressure. The reverse error is to label all adaptation a loss. A new edible target may diversify income and reduce waste. The relevant comparison asks whether net income, stability and safety improved relative to the counterfactual, and who had the capital, permits and market access to adjust.

Administrative records are especially ambiguous. Rising landings of a targeted non-indigenous species may reflect abundance, effort, participation, reporting, price or subsidy. Kilograms at a collection point are implementation output. Without standardised effort and an independent population index, they do not demonstrate population suppression; without ecological indicators, they do not demonstrate habitat or prey recovery.

A payment per kilogram may support income, make removal possible and generate biological samples. It may also redirect effort, change reporting or attract vessels with different catchability. Evaluation must specify the programme theory: which behaviour should change, which population process should follow, which ecological or livelihood outcome should result and over what period.

The Aegean scenarios in Chapter 6 make the time profile visible. Lower effort increased simulated biomass for many groups while reducing short-term catch. These are not forecasts for Paros, but they show why the capacity of small-scale operators to finance a transition is part of intervention design. Conservation, livelihood adjustment and invasive-species control may support one another, but each needs its own indicators.

7.5 What Markets Omit

Markets price exchanges under existing rules, not every consequence of ecological reorganisation. Food safety, disposal, inspection, bycatch, habitat condition, recreation and cultural attachment may lie outside sale price. A profitable transaction can coexist with external costs.

Public health creates a firm boundary. The toxicological evidence for *L. sceleratus* described in Chapter 5 establishes serious hazard in the sampled fish (Anastasiou et al., 2023). Prevention requires identification, communication and secure handling even when no poisoning occurs. Counting only clinical cases would miss both the value and cost of prevention.

For edible non-indigenous fish, market development may be explored subject to safety, traceability and ecological criteria. *L. sceleratus* is different: EU hygiene rules prohibit products derived from poisonous Tetraodontidae from being marketed (European Parliament and Council, 2004). Compensated removal is a closed chain of collection and disposal, not seafood commercialisation.

Non-market habitat values are harder to quantify. A canopy-forming assemblage may support biodiversity, nursery functions, landscape character and future options without generating an invoice when lost. Monetary valuation requires ecological quantities, affected beneficiaries and an appropriate method. Importing willingness-to-pay from another coast would create false precision; omitting an estimate is preferable if the omission is explicit rather than treated as zero.

Expenditure is not automatically benefit. Repair, monitoring and disposal create revenue and employment for suppliers, but resources used to respond to damage remain a social cost even when they are income to another actor. Distribution and net consequence must remain separate.

7.6 Models Are Conditional Ledgers

Models organise fragments of coupled systems. A food-web model represents flows that cannot all be manipulated; a value-chain model follows catch beyond the quay; a scenario asks how results change under altered effort, temperature or non-indigenous biomass. None has observed the future.

Corrales et al. (2018) modelled the Israeli shelf under combinations of fishing, warming and forced changes in alien-species biomass. Interactions could offset part of the ecological improvement produced by lower fishing pressure in other scenarios. This rejects simple addition. It does not show that lower effort will fail in the Aegean or that an imposed biomass multiplier represents a real invasion trajectory.

Ofir et al. (2026) extended that system into a seafood value chain. It asks whether changed catch composition affects producers, restaurants, profit and employment differently. Its ecological uncertainties are inherited from the food-web model, while the economic module cannot endogenously reproduce every shift in taste, technology, investment or regulation.

Three uncertainties must remain visible. Parameter uncertainty concerns values such as prices, diet proportions, costs and catchability. Structural uncertainty concerns organisms, enterprises, feedbacks and behaviours omitted or simplified. Scenario uncertainty concerns future emissions, effort, demand and policy that are not predictions in the first place. Narrow parameter intervals do not eliminate structural or scenario uncertainty.

Chakravorty et al. (2024) reviewed food-web models used to examine social and economic consequences of fisheries policy and environmental change. Ecological models organised trade-offs, but

social dimensions and explicit uncertainty remained comparatively underdeveloped. Appending prices to biomass does not by itself integrate institutions, behaviour and distribution.

Models should therefore be judged by role. They can test consequences of assumptions, reveal nonlinearities, compare designs and identify valuable measurements. Forecasting requires demonstrated performance and stable mechanisms; transfer to Paros requires local ecological, fleet and value-chain calibration. The Israeli numbers remain in Israel. The questions can travel.

7.7 Distribution Before Aggregation

Net benefit is the end of analysis, not its premise. Before aggregation, the account must identify winners and losers, timing, capacity to adapt and costs shifted outside the market. Equal monetary gain and loss across two groups may sum to zero while remaining socially consequential if rights, vulnerability and alternatives differ.

Greek consumer evidence illustrates opportunity and uncertainty. Minasidis et al. (2023) obtained 218 complete responses through an online, social-media-recruited survey. In this selected sample, 62% said they would consume a non-indigenous-fish product on a restaurant menu, 76% would buy such products if doing so protected the environment and native species, and 79% wanted quality certification. These are stated preferences, not purchases, willingness-to-pay estimates or evidence of population suppression. The sample was unusually young and highly educated relative to the national population.

Market creation can also change the management problem. Nuñez et al. (2012) argued that promoting consumption of invasive species may support removal but can create dependence on continuing supply or incentives to move and cultivate the target. This is a risk pathway, not proof that every market becomes perverse. A commercial route needs an ecological target, traceability, safeguards against spread and an exit rule if abundance declines.

Protection and transition should therefore be assessed on connected but separate axes. Ecological policy asks whether habitat, abundance, size structure or function improved relative to a counterfactual. Livelihood policy asks whether income, costs, safety and adaptive capacity changed, and for whom. Market policy asks whether a safe product found demand, who captured the margin and whether demand supported the ecological objective. Public-health policy asks whether exposure was prevented and handling remained secure.

Acting only after measured damage may miss slow or irreversible loss; acting solely on alarming scenarios can misallocate resources. A defensible middle course separates the threshold for precaution from the claim of fact. Reversible measures can begin under credible risk and explicit uncertainty.

Expensive or irreversible action requires stronger causal and distributional evidence, together with monitoring that can escalate, modify or stop the response.

7.8 Paros–Antiparos: The Missing Socioeconomic Link

No connected local series in the verified corpus joins ecological condition around Paros–Antiparos to fishing effort, catch composition, first-sale price, gear damage, vessel cost, household income, distribution, restaurants, employment and public expenditure. Fisher reports establish knowledge and interactions with non-indigenous species, but not a representative island annual cost. Regional evidence defines variables and mechanisms; it cannot fill the local ledger.

The missing link is not one number but four connected accounts: vessel effort, catch, damage and income; transactions and margins along the value chain; household exposure and adaptive capacity; and public administration, safety, disposal, enforcement and transfers. Ecological indicators must remain connected to the outcomes that expenditure is intended to change.

A baseline must precede strong valuation. One costly incident proves loss but not annual frequency. High landings prove production but not population trend. A survey reveals perception but does not reconstruct profit without quantities and costs. A model explores combinations but does not create missing observations.

The local audit therefore keeps provenance separate from evidential function. Direct observation, administrative transaction, structured self-report, historical testimony, derived estimate, conditional scenario and unresolved hypothesis describe how an item entered the record. The proposition itself is then classified as Observed, Reported, Testimonial, Estimated, Inferred, Mechanism or Unknown.

This discipline distinguishes where evidence supports protection, precaution, economic adjustment or a measurement gap. Chapter 8 now applies it to the complete local mosaic rather than to one ecological or economic pathway at a time.

Chapter 8 — Paros–Antiparos: A Local Test, Not a Local Verdict

The preceding chapters established how warming, biological invasions and fishing can interact across ecological and human systems. They also established an evidential limit: a mechanism demonstrated elsewhere, a basin-scale trend or a cost measured in another fishery does not become a local result merely because Paros and Antiparos lie within the same sea.

This chapter therefore changes the unit of analysis. It asks what can be said specifically about the Paros–Antiparos system from the evidence assembled for this study. The local record is not empty. It includes a standardised survey of shallow-water alien megabiota in 2011, older and later rocky-reef observations, a marine-cave survey in 2020, habitat mapping, seabird monitoring, structured reports from professional fishers and named historical testimony. Yet these sources differ in place, depth, season, method, measured variable and purpose. Their dates form a chronology, not a common ecological time series.

The governing conclusion is consequently narrow but substantive:

> **The local record is sufficient to reject ignorance and contains one species-specific breeding-colony signal, for Audouin's gull, but remains insufficient to establish a system-wide ecological trend, functional reorganisation or causal allocation.**

This distinction between baseline and diagnosis is central. The evidence shows that several components of ecological change have been observed in specified habitats and periods. Regional evidence shows that the islands lie within an Aegean environment undergoing sustained thermal and fishing pressure. Mechanistic studies identify processes capable of connecting those pressures to grazing, habitat condition and food-web change. What the corpus cannot yet establish is the current state of the whole island system, a common rate of change across its habitats, or the relative contribution of warming, alien species, fishing, anchoring, coastal development, water quality and other pressures.

8.1 The Rules of the Local Test

A result is treated as local only when its sampling frame or mapped footprint explicitly includes Paros, Antiparos or the immediately associated islets and waters. Cycladic evidence may provide a close analogue, southern-Aegean evidence may define regional exposure and Mediterranean research may establish a mechanism. None becomes a Parian observation without a documented spatial link.

The local evidence is separated into seven functional classes. **Observed** denotes a locally measured organism, habitat attribute or other variable under a stated method and date. **Reported** denotes either a participant's documented account or an institution's technical statement for which the underlying observations are not yet independently inspectable; the subtypes participant-reported and institution-

reported remain distinct. **Testimonial** is reserved for the author's historical account, preserved with provenance but not treated as a scientific sample. **Estimated** identifies quantities calculated from mapped or modelled data. **Inferred** identifies propositions made locally plausible by regional evidence. **Mechanism** denotes a process supported elsewhere that could produce the local pattern. **Unknown** identifies the missing denominator, comparison or time series needed to decide a proposition.

These are evidential profiles, not scores. They cannot be summed to manufacture confidence because geographical proximity cannot repair a mismatch in habitat, method, time or estimand. The same discipline applies to the main inferential chains. Surface temperature is not benthic thermal exposure. Vessel detection is not fishing mortality. Presence, persistence, establishment, spread and ecological impact are successive invasion claims, not synonyms.

The local test is thus deliberately asymmetric. Direct observations support precise statements about sampled places and periods. Regional evidence defines exposure and generates hypotheses. An absent local series does not erase regional risk, but regional risk cannot supply the missing local series.

8.2 The 2011 Shallow-Water Baseline

The clearest local ecological baseline remains the rapid assessment undertaken by Katsanevakis (2011). Fourteen randomly selected coastal stations around Paros and Antiparos were surveyed between 7 and 17 July 2011. Each received one hour of snorkelling effort across the shallow zero-to-ten-metre zone. The design sought conspicuous alien megabiota in habitats accessible to that protocol; it was not a census of all taxa, depths or seasons.

Eight taxa classified as alien in the original study were recorded: *Caulerpa cylindracea*, then reported as *Caulerpa racemosa* var. *cylindracea*, *Halophila stipulacea*, *Cassiopea andromeda*, *Pinctada radiata*, *Aplysia dactylomela*, *Percnon gibbesi*, *Siganus luridus* and *Fistularia commersonii*. The paper classified all eight as established under its operational criteria, which combined the survey with earlier records. That historical classification should remain attributed to the source. The single campaign observed presence; it did not by itself demonstrate self-sustaining populations. Current establishment would require evidence of persistence and sufficient reproduction or recruitment, while taxonomic and origin-status changes require comparison with harmonised inventories (Galanidi et al., 2023).

The study also recorded a useful negative result. *Lagocephalus sceleratus* had previously been reported from the islands but was not encountered during the 2011 survey. This was protocol-specific non-detection in one summer and one depth band, not evidence of island-wide absence or an estimate of abundance.

The most extensive fish observation was *S. luridus*, recorded at all 14 stations and described as the dominant herbivorous fish. Extensive barrens with little erect macroalgal vegetation were also reported.

The paired observation is important: a non-indigenous herbivore was widespread in the sampled shallows, and low-vegetation states were visible during the same campaign. It does not allocate the barrens to rabbitfish. Bite rates, grazer exclusions, historical algal cover and competing pressures were not measured. Native urchins, fishing-mediated food-web effects, heat, physical disturbance, nutrients, wave exposure and recruitment all remain plausible contributors.

The study's enduring value is therefore methodological. It provides dated station points, a station-by-taxon matrix and a recoverable survey design. A carefully governed repetition could estimate differences in detection under comparable effort. Until such a repetition exists, the 2011 record is a baseline, not a trend.

8.3 Rocky Reefs Without a Common Series

The rocky-reef archive is broader in ecological content but fragmented in design. In October 2000, four quantitative samples of upper-sublittoral macroalgae were collected at Despotiko at a reported mean depth of 0.25 metres within the development and calibration of the continuous Ecological Evaluation Index (Orfanidis, Panayotidis and Ugland, 2011). This confirms local sampling and the site's role as a putative reference location. The published table does not provide a local score, species list or cover values, so it cannot support a Despotiko-wide condition estimate.

Surveys in 2007–2008 supplied a second historical snapshot at Strongylo, south of Antiparos. The islet had the lowest reported mean fish biomass in the 25-island comparison, 0.06 kilograms per 125 square metres, while *Cystoseira* assemblages dominated the sampled sites (Giakoumi et al., 2012; Giakoumi and Kokkoris, 2013). These are direct observations from a small southern islet. They are not estimates for the main coasts, and the public results do not permit a local trend or attribution of the low biomass to fishing alone.

A 2016 Aegean survey adds a recoverable fish-sampling link at Santa Maria and Ebriokastro. Sini et al. (2019) used underwater visual census at five and fifteen metres to compare sites classified as experiencing different small-scale fishing pressure. Two supplementary coordinates coincide with the later reef stations, although their place names conflict with their north-eastern Paros positions. The inconsistency remains a source warning. Because the published biological results are pooled, these records identify potentially recoverable local data, not a Paros-specific abundance estimate or causal effect.

The strongest later benthic evidence comes from Savin et al. (2023). Four of the study's rocky stations lie within the Paros–Antiparos system: Ebriokastro, Santa Maria, Pantieronisi and Petalida. Their mean values under the vegetation-restricted reef-EBQI implementation were 0.96, 0.49, 3.35 and 1.44 respectively, all within the category labelled "Bad".

The measured object must remain visible. The values classify macroalgal vegetation at specified stations. They do not measure whole-reef biodiversity, fish abundance, water quality or ecosystem services, and they do not represent every rocky shore. The regional programme sampled in 2016 and 2020, but the public supplement does not unambiguously assign a year to every local station. At shallow Pantieronisi, EEI-c produced a category different from the vegetation-restricted reef-EBQI, illustrating that indicator labels cannot be separated from their metric, depth, component and reference framework.

These four stations do not repeat the 14-station 2011 survey. Comparing them can generate a hypothesis about persistent grazing or other pressures, but not a before-and-after result. Cycladic experiments and spatial studies make grazing by rabbitfish and sea urchins a credible mechanism (Giakoumi, 2014; Nikolaou et al., 2023; Wong et al., 2026). They do not identify the cause of the four local index values. That would require synchronised observations of herbivores, urchins, grazing, algal structure, temperature, habitat and competing pressures.

8.4 Specialised Habitats and Upper-Trophic Records

The Pantieronisi marine cave supplies a narrow but unusually specific record. During an August 2020 dive at approximately 14 metres, two individuals of the Indo-Pacific shrimp *Urocaridella pulchella* were recorded, including one ovigerous female (Digenis et al., 2021). A later comparison of 27 Greek marine caves used the same local field event. It reported eight taxa and 264 individuals at the entrance, nine taxa and 36 individuals in the semi-dark zone, and four taxa and 61 individuals in the dark zone (Digenis et al., 2025).

The two publications are not independent temporal observations. Together they provide strong evidence of presence at a specified place, depth and date. The ovigerous female demonstrates reproductive condition, not confirmed local hatching, recruitment, persistence or establishment. No ecological effect was measured. The cave is also a specialised habitat whose assemblage cannot be used to estimate prevalence along the open coast.

At the upper end of the local food web, official Important Bird Area and LIFE records report, principally over 2005–2012, 50–65 breeding pairs of Mediterranean shag, 100–160 pairs of Scopoli’s shearwater, 20–50 pairs of Yelkouan shearwater and 10–15 pairs of European storm petrel in 2012 (Fric et al., 2012; European Commission LIFE, 2012). Fric et al. also identify the clearest genuine local temporal signal: Audouin’s gull first bred locally in 1996, remained relatively stable through 2001, then declined sharply and was absent in the final years approaching 2012. The cause was not established. Colony movement, competition, breeding-site condition, prey, bycatch and disturbance cannot be separated from the available record.

This is a species-specific breeding-colony history, not a direct fish-abundance series or a whole-system trophic indicator. Its value lies precisely in the fact that it is temporal, local and bounded.

8.5 Seagrass: Extent, Identity and Condition

The seagrass record contains several different objects that should not be collapsed. A detailed historical habitat map exists for Natura 2000 site GR4220017. A later Landsat comparison measured partial spatial agreement with that reference, but product agreement is not habitat loss. The protected-site footprint is also not the entire Paros–Antiparos marine system.

For the project's declared bounding box, the reproducible MA8-01 calculation extracted 158 intersecting mapped-seagrass features and produced a non-overlapping planar union of 36.813696 square kilometres, reported narratively as approximately 36.8 square kilometres. Of the extracted records, 151 carry 2016 and seven carry 2018 in the dataset's Year field, whose meaning is not documented as an imagery or field-survey year. The estimate is an auditable area of a mapped category within a stated dataset, version, projection and clipping rule. It is not a measurement of present healthy *Posidonia oceanica*, map accuracy, species identity or ecological condition.

An institution-reported mission undertaken in 2023 and announced in January 2024 described 174.57 square kilometres of seabed surveyed, extensive meadows and signs of degradation and anchor scarring in two bays. Surveyed seabed is not seagrass extent. Without the underlying spatial layer, sampling protocol, condition metrics and uncertainty, the statement cannot independently establish island-wide meadow area or trend.

The local corpus therefore supports the existence of substantial mapped seagrass habitat and identifies anchoring as a plausible direct pressure in specified bays. It does not quantify current condition, fragmentation, loss or the share attributable to anchoring, warming, water quality or coastal development.

8.6 Regional Exposure and the Local Denominator

Long-term environmental evidence is strongest at regional scale. Satellite and reanalysis studies document sustained warming and changing marine-heatwave characteristics across the Mediterranean and Aegean (Dayan et al., 2023; Denaxa et al., 2025). Higher-resolution Copernicus products can describe the recent surface environment and place local observations within a regional anomaly. They remain remotely sensed, blended or modelled products. Grid spacing does not equal independent effective resolution, and surface or layer-integrated temperature does not measure the exposure of an organism in a bay, cave or meadow at a specified depth.

The permitted inference is therefore probabilistic. Regional warming increases the plausibility of thermal filtering, prolonged suitability for warm-affiliated species and increased stress on native organisms. It does not show that temperature caused any local reef category, cave occurrence or fishery report. Cumulative-impact models can identify candidate priorities, but predicted distributions and transferred weights do not constitute observed local loss.

Fishing presents a similar denominator problem. The reconstructed Greek catch series for 1950–2022 shows that official landings omitted important components and estimated historical total catch to have been understated by more than 25 per cent (Touloumis et al., 2026). That is a national reconstruction with explicit assumptions, not a Parian correction factor or an abundance series. AIS and radar studies reveal mobile fleets, mismatches between vessel origin and fishing location, and substantial predicted activity within Aegean management areas (Armelloni et al., 2021; Marsaglia et al., 2025). They do not quantify removals, fishing mortality, legality or ecological effect around Paros, and they are least complete for small coastal vessels.

The most direct local social evidence comes from interviews with professional vessel owners or skippers at seven Greek ports, including Paros (Moutopoulos et al., 2025). Paros respondents described interactions with non-indigenous species and gear damage associated with *S. luridus*. These structured reports document experienced interactions. They do not provide a resolved local denominator, catch per unit effort, abundance or annual economic loss.

The project's AT-01 provenance stream preserves two named retrospective observations by the author. Bill Marangozis recalls substantially fewer visually encountered fish during repeated visits to Aspros Gremos in 2023 than during his earlier experience through 1983. He also recalls no large fish during one organised dive at Pantieronisi in July 2008. The remembered density figures are mental snapshots rather than contemporaneous counts, and the second account concerns one dive. The testimony identifies places, periods and variables worthy of investigation. It does not establish a percentage decline, standardised density, biomass, island-wide trend, fishing effect or causal allocation.

The missing denominator is thus explicit. The assembled corpus contains no aligned local series of depth-specific temperature, fish size and biomass, gear-specific professional and recreational effort, total removals, discards, benthic condition, seagrass condition and human consequences. This does not prove that no institution or researcher holds relevant unpublished data. It means that the present study cannot use such data until they are located and made methodologically interpretable.

8.7 The Local Evidence Ledger

The following ledger records the strongest conclusion supported by each local evidence object and the boundary that must remain attached to it.

Ledger ID	Class	Supported local proposition	Principal boundary
LE8-01	Observed	Eight alien taxa were recorded at 14 shallow stations in July 2011; the original study classified them as established under its criteria.	Presence in one campaign does not independently prove self-sustaining populations, current status or trend.
LE8-02	Observed	*Siganus luridus* occurred at all 14 stations and extensive barrens were observed.	Co-occurrence does not allocate the barrens to rabbitfish or quantify effect.
LE8-03	Observed	Earlier local records of *Lagocephalus sceleratus* were reported, while the species was not detected in the 14 shallow stations in July 2011.	Protocol-specific non-detection does not establish current absence or abundance.
LE8-04	Observed	Four shallow macroalgal samples were collected at Despotiko in 2000 within an EEI-c reference-site exercise.	No published local score, species list or cover values support a site-wide estimate.
LE8-05	Observed	Strongylo supplied a 2007–2008 rocky-reef snapshot with low mean fish biomass in the island comparison and *Cystoseira*-dominated sampled assemblages.	A small-islet snapshot is not a main-island trend or proof of fishing causation.
LE8-06	Observed	Two 2016 fish-survey coordinates coincide with Santa Maria and Ebriokastro.	Published outcomes are pooled, and source place names conflict with coordinates.
LE8-07	Observed	Four specified rocky stations had vegetation-restricted reef-EBQI values in the category “Bad”.	The result is neither whole-reef nor island-wide status, and the year is unresolved for every station.
LE8-08	Observed	The Pantieronisi cave survey produced a zone-specific motile-fauna snapshot in 2020.	One specialist-habitat visit is not a coast-wide estimate or temporal replication.
LE8-09	Observed	Two *Urocaridella pulchella*, including an ovigerous female, were recorded in the cave.	Presence and reproductive condition do not prove persistence, spread or impact.
LE8-10	Observed	Official records document several seabird breeding populations and a temporal decline and later absence of the local Audouin’s-gull colony approaching 2012.	The cause was not established, and the record is not a direct fish-availability index.
LE8-11	Estimated	Historical habitat mapping exists for Natura site GR4220017, and a later product measured partial spatial agreement.	Product agreement is not habitat loss, and the site is not the whole island system.
LE8-12	Estimated	The project reproduced a 36.813696-square-kilometre union of mapped-seagrass features within its declared bounding box.	Mapped-category area is not current healthy *Posidonia* area, field condition or trend.
LE8-13	Reported	A 2023 mission reported 174.57 square kilometres of seabed surveyed, extensive meadows and degradation and anchor scarring in two bays.	Surveyed seabed is not meadow extent; the underlying methods and layers are not publicly inspectable.
LE8-14	Reported	Professional respondents from Paros described NIS interactions and gear damage associated with *S. luridus*.	Participant reports lack a resolved island denominator, CPUE or annual-cost estimate.
LE8-15	Testimonial	Bill Marangozis supplied named retrospective accounts of fewer fish at Aspros Gremos in 2023 than through 1983 and no recalled large fish during one Pantieronisi dive in 2008.	Named testimony is not standardised ecological sampling or evidence of causation.

Ledger ID	Class	Supported local proposition	Principal boundary
LE8-16	Inferred	The islands lie within a regional setting of long-term surface warming, marine heatwaves and changing upper-ocean conditions.	Regional exposure is not local benthic temperature or biological effect.
LE8-17	Mechanism	Rabbitfish and urchin grazing can plausibly contribute to low-canopy or barren rocky states.	No synchronised local test allocates the observed condition among grazers and competing pressures.
LE8-18	Unknown	Present representative abundance, biomass and distribution of priority non-indigenous taxa.	No repeated, habitat-stratified contemporary survey.
LE8-19	Unknown	Change since 2011 or the later reef and cave observations.	No method-matched local time series.
LE8-20	Unknown	Local fish size, age structure and food-web composition through time.	No aligned fishery-independent series or cohort reconstruction.
LE8-21	Unknown	Current seagrass identity, condition, fragmentation and trend across the mapped features.	Mapping has not been converted into representative field assessment.
LE8-22	Unknown	Gear-specific fishing effort, total removals and net socioeconomic consequence.	Professional, recreational, discard, price and cost ledgers are not linked locally.
LE8-23	Unknown	Relative contribution of warming, alien species, fishing, urchins, anchoring, development, water quality and other pressures.	Current snapshots supply neither a counterfactual nor synchronised causal variables.

The ledger covers all seven evidential classes without converting testimony into scientific measurement or counting local subsets and regional summaries as independent confirmation.

8.8 What the Mosaic Supports

Four local hypotheses remain scientifically credible. Regional warming may be increasing thermal suitability for warm-affiliated species and stress on native organisms. Rabbitfish and urchin grazing may contribute to persistent low-canopy states in some rocky habitats. Warming, ecological redistribution and fishing pressure may jointly alter the fish sizes and abundance encountered by local users. Prey, bycatch, breeding-site condition, competition and movement may jointly influence the history of specialised marine birds.

None of these causal propositions has yet been quantified or allocated locally. A system-wide verdict would require comparable measurements across principal habitats and trophic components, an estimate of change and evidence capable of separating competing explanations. The present mosaic instead supplies dated baselines, direct observations, one species-specific temporal signal, regional exposure, testable mechanisms and a precise register of missing denominators.

That is a substantive outcome. It replaces the false choice between claiming that nothing is known and pretending that fragmented observations already prove ecological reorganisation. The next task is not to add every conceivable measurement. It is to preserve the baselines, recover the most consequential

missing material and develop a research and management architecture in which each future observation answers a declared question.

Chapter 9 — A Research and Management Agenda under Uncertainty

Chapter 8 ended without a system-wide local verdict. That was its result, not its failure. The dated observations, recoverable stations, mapped habitats, professional reports and historical testimony remain largely incomparable because they differ in place, depth, season, method and measured object. They should neither be forced into a trend nor make publication contingent on a field programme that has not been authorised. The present study is complete on the evidence available at its documentary cut-off; new measurements would test or revise its conclusions in a future empirical phase.

This chapter therefore presents a long-term research and management agenda, not an immediate operational protocol. Its governing proposition is:

> **Uncertainty should determine what is measured, how strongly results are interpreted and how reversible decisions should be. It should neither justify inaction nor license arbitrary certainty.**

The agenda has three purposes. First, it preserves the historical record so that it can be revisited without manufacturing comparability. Second, it identifies the smallest linked set of observations capable of distinguishing major competing explanations. Third, it connects future evidence to proportionate decisions while keeping ecological status, causation and policy performance separate.

9.1 From Evidential Thresholds to Decision Questions

The four evidential thresholds defined in Chapter 2 concern documented state, compositional change, functional change and causal attribution. Management adds a further distinction by separating what is observed from how evidence should guide action. Four questions must therefore remain explicit:

1. **Observation:** was a taxon, temperature, length, catch or habitat attribute measured reliably?
2. **Status or change:** how does it compare with a declared historical baseline, contemporary reference or threshold?
3. **Attribution:** which pressure, interaction or intervention best explains the difference?
4. **Action:** what response is proportionate to the potential harm, cost of delay, reversibility and distributional effect?

The questions need not advance together. An alien species may be securely identified before persistence or impact is known. A low-canopy reef can be documented before grazing is established as its cause. A public-health hazard may justify immediate communication without a complete ecosystem model.

Uncertainty is also multidimensional. It includes measurement error, observer variation, imperfect detection, sampling variance, spatial and seasonal coverage, model structure, missing data, uncertain baselines and uncertain thresholds. A non-detection after inadequate effort is not equivalent to a well-powered estimate close to zero. A more accurate new method can still break a series if it is introduced without overlap.

Future work should therefore define the **estimand** before selecting the instrument. “Fish are declining” is not an estimand. Density of specified taxa under a defined visual-census method, a standardised length-spectrum indicator or gear-specific retained catch per unit of effort can be. Each requires a spatial population, sampling unit, period, effort denominator and minimum change that would alter a decision. Where feasible resources cannot resolve that change, the work should be labelled exploratory rather than interpreted as evidence of stability.

9.2 The Publication Boundary and the Research Boundary

The empirical programme developed during this project remains a separate future stream. Production fieldwork is not authorised. The 14-station 2011 survey and the four later rocky-reef stations are distinct analytical panels and must not be pooled into a composite before-and-after index. The published points do not by themselves recover route geometry, observer behaviour, exact effort or all station dates. The reef record has separate unresolved questions concerning season, image allocation and index implementation.

The correct near-term task is therefore preservation and controlled recovery:

- retain immutable identifiers for the 14 shallow stations and four rocky-reef stations;
- preserve the published station-by-taxon matrix and local reef values without presenting them to field observers as expected outcomes;
- seek route geometry, raw observations, observer notes, taxonomic decisions, reef images and calculation rules from the original researchers or archives;
- maintain separate raw, validated and interpreted data layers;
- freeze estimands, exclusions, quality rules and provenance before confirmatory analysis;
- complete specialist, safety, permitting and data-governance review before any production deployment.

These actions improve readiness without changing the evidential status of the current manuscript. A future resurvey can estimate detection or persistence at sampled stations under declared effort. It cannot, from two dates alone, establish causation, an island-wide trend or absence from non-detection.

9.3 Priority I: Recover and Revisit the Baselines

The first research priority is to protect the possibility of valid comparison. The 2011 shallow-water survey offers the strongest candidate because its 14 station points, July window, one-hour snorkelling effort, zero-to-ten-metre depth envelope and detection matrix are published (Katsanevakis, 2011). Until the remaining geometry and observer rules are recovered or governed by explicit reconstruction decisions, any future work should be described as a historical-coordinate resurvey rather than an exact replication.

Its proper outcomes would be station-level detection and encounter measures under declared effort. Repeated visits within a future design could estimate detectability. Repeated detection would support persistence at a sampled station; non-detection would remain conditional on effort and detection probability. The 2011 condition was not pristine, since widespread *S. luridus* and barrens were already present.

The rocky-reef panel requires its own logic. Ebriokastro, Santa Maria, Pantieronisi and Petalida should be revisited only after the historical season, depth support, image allocation and index calculation are sufficiently resolved. Five metres is the only common depth among all four stations. A July visit would create a new July baseline unless it could be reconciled with the historical season. Fish data from Santa Maria and Ebriokastro may provide an additional method-specific lane after the name and coordinate inconsistency is resolved (Sini et al., 2019; Savin et al., 2023).

Any improved method, whether video, environmental DNA, expanded depth coverage or a fuller reef index, should form an enhancement lane. It may eventually become the preferred operational method, but it should overlap with the historical lane long enough to estimate the break in measurement rather than conceal it.

9.4 Priority II: Align Exposure, Ecological State and Fishing

The central causal problem cannot be solved by repeating historical observations alone. Future work should align, at compatible places and times, the variables that distinguish the leading explanations.

For rocky reefs, this means measuring fish identity and size, rabbitfish and native herbivores, sea-urchin abundance and size, macroalgal canopy and turf, recruitment, grazing behaviour, depth, exposure, habitat structure, temperature and visible local disturbance. The aim is not to award causal shares after one campaign. It is to determine whether low-canopy states co-vary through time with grazers, heat, habitat disturbance or another measured pressure.

Thermal monitoring should privilege organismal depth and habitat over surface resolution alone. A future array could use calibrated hourly loggers across an exposed-rock depth profile and selected

sheltered, seagrass and cave settings, following established Mediterranean practice (Garrabou, Bensoussan and Azzurro, 2018). Regional satellite and reanalysis products would provide context and quality checks, not substitute benthic exposure. Raw records, calibration, drift, depth and attachment metadata would remain immutable. Temperature would still be an exposure variable, not a direct measurement of mortality, growth or reproduction.

Fishing requires two linked but non-substitutable series. A fishery-independent ecological series can estimate local fish density and length structure under declared habitat and visibility conditions. A stable, anonymised fisheries panel can record gear-specific effort, retained and discarded catch, length samples, damage, costs and unusual species interactions. Catch per unit effort must be standardised for gear, targeting, vessel, season, area and changes in fishing power before it is interpreted as an abundance index (Hoyle et al., 2024).

Professional and recreational fishing require separate sampling frames and effort units. A local convenience survey can reveal practices and improve questionnaire design but cannot estimate total removals. Existing national, cooperative and administrative data should be examined before new reporting burdens are created, with their coverage and confidentiality limits made explicit (Grati et al., 2021).

Agreement between declining standardised CPUE and a fishery-independent decline would strengthen a population-change inference. Divergence would be equally informative because it could identify altered targeting, catchability, spatial access or panel composition. The purpose of linkage is diagnosis, not forced agreement.

9.5 Priority III: Habitat, Persistence and Upper-Trophic Response

Seagrass research should preserve the distinction among mapped extent, species occupancy, ecological condition and change. Historical mapping and the reproduced 36.813696-square-kilometre union can define candidate strata, not current healthy *Posidonia* area. A future representative design would need field confirmation within and outside mapped polygons, repeated boundary observations and condition measures under an agreed protocol. Map differences would require reconciliation of sensor, classification, positional and seasonal error before being labelled habitat loss.

The non-indigenous-species agenda should combine the historical shallow panel, high-detection locations such as ports and marinas, and specialist habitats such as Pantieronisi cave. These station types answer different questions. Hotspots improve early detection but not island-wide abundance estimates. A cave repeat can test repeated detection of *Urocaridella pulchella* under comparable zones and effort. Every record should retain the invasion stage it supports: presence, persistence and

establishment, spread or ecological impact. Increasing reports may indicate increasing observation, and impact requires a measured native or functional response.

The historical seabird record justifies a linked upper-trophic module, subject to specialist capacity and permissions. Compatible colony counts and breeding-success measures could update the status of Audouin's gull and other monitored species. Diet, movement, bycatch and disturbance would remain separate substreams because each has different sampling bias. A colony change would update a species and site; it would not automatically diagnose underwater prey abundance or the whole marine food web.

Even completion of these priorities would not, by itself, reconstruct a new local food web. A strong trophic-network claim would require local dietary evidence, stable isotopes or metabarcoding and, ultimately, a calibrated flow model capable of estimating interactions rather than merely listing components. The phrase "the new food web of Paros" therefore remains a research question, not a finding of this study.

9.6 Human Consequences and Intervention Evaluation

Ecological change becomes a human consequence through particular assets, activities and institutions. Future socioeconomic work should therefore retain four ledgers:

- a **vessel ledger** for catch, effort, damage, repair, fuel, labour, avoidance and the allocation of income;
- a **transaction and value-chain ledger** for quantities, prices, handling, processing, wholesale, retail and restaurant outcomes;
- a **household ledger** for income, consumption, unpaid work, risk and adaptation;
- a **public ledger** for administration, monitoring, compensation, disposal, enforcement and health communication.

Each entry requires a bearer, geography, period and counterfactual. A lower repair bill may indicate less damage or abandonment of a ground. Compensation is income to a participant and public expenditure, not automatically net social benefit. Kilograms delivered under a removal programme are an implementation output, not evidence of population control. Population response requires an independent index; livelihood success requires income, behaviour and distributional outcomes.

Interventions should consequently be evaluated through separate chains for ecological protection, livelihood adjustment, safe market development for legally edible species and public-health protection. Success in one chain does not prove success in another. This is particularly important for *Lagocephalus sceleratus*, for which removal and compensation may serve risk or income objectives without

demonstrating population suppression, while poisonous Tetraodontidae remain excluded from the EU food market.

Fishers, divers, residents, businesses and public bodies should participate in defining feasible effort units, missing costs and workable interventions. Their knowledge remains attributed to its mode of production. Co-design strengthens relevance; it does not convert reports into ecological measurements.

9.7 Analysis and Evidence Infrastructure

Any future confirmatory cycle should be governed by a pre-analysis plan specifying primary estimands, units, minimum important changes, inclusion and exclusion rules, covariates, missing-data treatment, candidate models and decision outputs. Exploratory work remains valuable but should be labelled after the fact.

The analysis must preserve hierarchy. Quadrats are nested within transects, transects within stations, stations within habitats and visits within years. Several observations at one station are not several independent coasts. Historical and sentinel stations improve sensitivity to local trajectories; spatially balanced probability sites broaden inference. Their roles can complement one another but cannot be pooled without their sampling design.

Attribution requires temporal order, aligned exposure and response and, where possible, multiple pressure and reference locations or multiple pre-intervention observations. Open marine systems rarely offer untouched controls. The credible object is usually a comparative counterfactual estimate under stated assumptions.

The evidence infrastructure should preserve:

- immutable raw observations and media;
- stable identifiers for stations, visits, samples, taxa, vessels and interventions;
- historical and current taxonomic names with reference identifiers and dates;
- effort, units, detection method and quality flags;
- coordinates, spatial reference and uncertainty;
- calibration and processing history;
- versioned code, data dictionaries, checksums and change logs;
- a link from every published result to its source rows and analysis version.

Confidential fisheries coordinates and commercial or personal records require controlled access and aggregation. Confidentiality does not remove the need to document method, coverage and uncertainty. Every report should begin with a comparability audit: which stations were sampled, which methods changed, what data were lost, whether observers were calibrated and whether the composition of

participating vessels changed. Inadequate coverage must not be coded as ecological improvement, and failure to detect change must not be called stability without reference to statistical power.

9.8 Decision Rules for Adaptive Management

Monitoring becomes management only when evidence is connected to pre-agreed responses. Four gates preserve the distinction among observation, change, attribution and action.

Gate	Required evidence	Permitted conclusion or response	Prohibited shortcut
A: Data adequacy	Valid method, calibration, effort, coverage and detection assessment	Accept an observation, record protocol-specific non-detection or mark it not assessable	Treat inadequate data as favourable status
B: Status or change	Declared estimand, comparator or threshold, uncertainty and detectable change	Describe condition, difference or trend at the supported scale	Infer cause from status alone
C: Attribution	Temporal order, aligned exposure and response, comparison or intervention contrast, mechanism and alternatives	State the degree of support for a specified pressure or intervention effect	Allocate causal shares from co-occurrence
D: Action	Consequence, reversibility, costs of delay and error, distribution and review rule	Continue, verify, take reversible precaution, escalate, modify or stop	Claim that action proves the causal diagnosis

Gate A is fundamental. A failed logger, incomplete vessel panel or low-visibility census is **not assessable**, not evidence of no heat, no fishing pressure or no fish.

At Gate B, a historical baseline, contemporary comparison, ecological or institutional threshold and project action level must remain distinct. A local project may create operational triggers, but it cannot relabel them as official MSFD or IMAP Good Environmental Status thresholds.

Operational signals may progress from routine observation to verification, confirmed change, attributed response and emergency override. Numerical effect sizes or probabilities should be chosen before the relevant results are seen and should reflect the costs of false reassurance and false alarm. Chronic ecological claims normally require persistence or spatial replication. A verified toxic, mortality or safety event may justify immediate protection while investigation continues.

Precaution is strongest when paired with reversibility. Temporary anchoring controls, rapid confirmation of a harmful taxon or time-limited protection of a breeding site can be justified by credible risk before complete attribution, provided that the measure states its expected pathway, affected groups, duration and review rule. More coercive, costly or irreversible measures require stronger evidence unless the expected harm of delay is itself severe and irreversible.

Every intervention should specify what behaviour or pressure it seeks to change, the expected ecological pathway, the likely human distributional effects and the evidence that would lead managers to continue, escalate, modify or stop. Adaptive management is not permission to change criteria after seeing inconvenient results. It is a documented cycle of objectives, alternative actions, predicted outcomes, monitoring, model updating and renewed decision (Williams, Szaro and Shapiro, 2009).

9.9 A Staged Path Forward

The agenda should develop in stages rather than as a single large field campaign.

Stage	Purpose	Evidential product	Boundary
Preservation and recovery	Secure stations, historical materials, taxonomy, methods, permissions and governance	Auditable baseline archive and explicit unresolved gates	No new ecological trend
Pilot and calibration	Estimate variance, detectability, observer effects and operational feasibility	Validated methods and realistic power estimates	Exploratory results only unless pre-specified criteria are met
Repeated local observation	Build compatible series for exposure, ecological state, fishing and selected habitats	Local trajectories at supported stations and strata	Not automatic island-wide representation or causation
Representative assessment	Add a spatially balanced habitat frame	Present-condition estimates for declared populations	Historical change only where comparability exists
Intervention evaluation	Observe multiple pre- and post-action periods with comparable locations	Evidence about effectiveness, displacement, cost and distribution	No guarantee of success beyond the evaluated setting

The stages are logical rather than calendar promises. Source recovery or expert guidance may improve replication before fieldwork begins. Poor precision may require redesign. An acute hazard may require immediate response. None of these possibilities makes new data a precondition for publication of the present study.

The first future act should remain modest and exact: preserve the 14 published WGS84 station points and their station-by-taxon matrix, continue seeking the unpublished route and effort material, and keep any historical-coordinate resurvey separate from methodological enhancements. The four rocky-reef stations require their own seasonal and image-recovery decisions. This will not resolve five decades of ecological change. It will ensure that future observations reduce declared uncertainties rather than merely enlarge the archive.

The study therefore closes with neither a prediction of collapse nor an assurance of stability. It offers a more defensible position. Paros and Antiparos are embedded in a changing regional sea, and local observations already show ecologically consequential elements of that change. Yet the available

evidence does not establish the magnitude, trajectory or causal composition of system-wide reorganisation. The appropriate response is sustained, comparable and decision-linked inquiry, combined with proportionate action where delay could increase serious or irreversible harm.

Conclusion: A Changing Sea and the Discipline of Knowing

This study began with an apparently simple question: is the familiar sea around Paros and Antiparos becoming a different ecological system? The evidence supports a qualified answer. The Mediterranean and Aegean are undergoing a well-documented thermal and ecological transition, and processes capable of reorganising species composition, trophic interactions and human uses of the sea are already present within the Paros–Antiparos system. The assembled local record, however, does not yet demonstrate a representative system-wide trajectory, reconstruct a changed food web or allocate the relative contribution of the pressures involved.

That distinction is the study's central conclusion. Regional change is not a local verdict, but neither is local discontinuity evidence of stability. The islands lie within a warming sea exposed to marine heatwaves, biological redistribution, introduction pathways and long histories of fishing and coastal use. Local observations document widespread rabbitfish in sampled shallows in 2011, low macroalgal status at four later rocky stations, a specialised cave occurrence, mapped seagrass habitat, professional reports of interactions with non-indigenous species and a temporal decline in one breeding seabird population. Each is real within its design. Their combination establishes an evidence mosaic, not a common ecological time series.

The first substantive correction offered by the study is to separate arrival from impact. Transport pathways deliver organisms; environmental and biological filters govern survival, establishment and spread; ecological consequence requires an additional measured response. Warming can increase thermal suitability and alter competitive or demographic conditions, but it does not carry organisms through a canal or on a hull, and it does not dictate the same outcome for every species. Inventories remain indispensable records of occurrence and validation, yet their growth reflects detection and taxonomic history as well as biological expansion.

The second correction is to separate mechanism from local attribution. Rabbitfish grazing can maintain low-algal states under experimentally demonstrated conditions, and sea urchins can perform the corresponding function elsewhere. These findings make altered grazing a credible explanation for some low-canopy reefs. They do not establish which consumer created or maintains the condition of a particular Parian station, nor do they exclude heat, fishing, anchoring, pollution, sedimentation or limitations on algal recruitment. The local grazing hypothesis is therefore not weak. It is well formed, mechanistically supported and still untested at the scale at which the causal claim would be made.

The toadfish case shows why impacts should not be forced into a common ecological template. *Lagocephalus sceleratus* is integrated into eastern Mediterranean trophic networks, but the strongest immediate evidence concerns toxicity and operational damage rather than a measured local trophic

cascade. Public-health action is justified by hazard and exposure pathways, not by proof that prey populations have declined. Removal programmes likewise require several separate judgements: whether they reduce population pressure, compensate fishers, improve safety and distribute public resources fairly. A kilogram landed is an administrative output until those distinct outcomes are measured.

The third correction is to place fishing inside the ecological explanation rather than outside it. Fishing changes which individuals, sizes and functions remain in the water while responding to markets, regulation, technology and the redistribution of species. Climate change therefore acts on an already selected community. Yet official landings, reconstructed catches, diver observations and fishers' memories do not measure the same quantity. Without effort, habitat, gear, detection and reporting denominators, apparent biological trends may partly reflect a changing observation system. The expansion of Greek statistical coverage after 2016 is a particularly clear warning against reading administrative discontinuity as ecological recovery.

Human consequences deepen this problem because ecological change does not enter society through a single balance sheet. Damage, lost catch, food safety, habitat value, adaptation, compensation and new market opportunities fall on different people and institutions. The same response can be income to one actor, cost to another and a transfer rather than a net social gain. For this reason, distribution must precede aggregation, and ecological success must remain separate from commercial turnover or programme expenditure.

What, then, can be concluded specifically for Paros and Antiparos? The local evidence excludes the claim that too little is known to identify meaningful baselines or research priorities. The 2011 survey provides a recoverable shallow-water reference. The rocky-reef, cave, seabird and habitat records identify additional components and places that merit protection or repeated observation. Fisher reports and historical testimony contribute questions, locations and consequences that short scientific campaigns may overlook. The evidence is sufficient to frame credible hypotheses and to justify proportionate, reversible action in the presence of serious risk.

It is not sufficient to claim that the islands have undergone a quantified system-wide reorganisation, that rabbitfish caused the observed condition of their reefs, that local fish have become smaller because of warming or fishing, or that a new food web has been reconstructed. These propositions require comparable observations across time, aligned ecological and pressure variables, and designs capable of examining serious alternatives. The absence of those designs is not a rhetorical caveat added after the conclusion. It is part of the conclusion itself.

The research agenda follows directly from this diagnosis. The immediate priority is to preserve the possibility of comparison: secure station identities, recover original methods and materials, maintain

historical and enhanced measurement lanes, and specify the quantity to be estimated before collecting data. Repeated observations should link thermal exposure, benthic state, fish and grazer size structure, professional and recreational fishing effort, habitat condition and human consequences without pooling incompatible panels. Representative assessment, causal attribution and intervention evaluation are later and distinct achievements.

Management under these conditions requires evidential discipline rather than passivity. Observation, change, attribution and action are separate gates. A public authority may act before complete attribution when a hazard is verified or the potential harm is serious, difficult to reverse and addressable through a proportionate measure. Such action should state its objective, expected pathway, affected groups, duration and rule for review. Precaution is most defensible when it remains transparent, reversible and capable of learning from its own results.

The larger significance of the Paros–Antiparos case lies in its resistance to two equally misleading stories. One story converts regional warming, new species and remembered scarcity into a completed local narrative of decline. The other treats the absence of a continuous monitoring series as evidence that no consequential change can be known or managed. The local evidence supports neither position. It shows a sea connected to a profound regional transition, containing dated signs of ecological and human consequence, but observed through an archive that is fragmented across habitats, methods and generations.

The most credible conclusion is therefore also the most demanding. Paros and Antiparos should not be described as ecologically unchanged, nor should they be declared a reconstructed ecosystem on the basis of evidence that cannot support the claim. They should be understood as an island system within a changing sea whose historical baselines are still recoverable, whose present condition can still be measured and whose future management can still be improved. Scientific restraint, in this setting, is not hesitation. It is the discipline that makes early warning credible, comparison possible and proportionate action defensible.

References

Anastasiou, T.I. et al. (2023) 'Assessing the toxicity of *Lagocephalus sceleratus* pufferfish from the Southeastern Aegean Sea and the relationship of tetrodotoxin with gonadal hormones', *Marine Drugs*, 21(10), 520. https://doi.org/10.3390/md21100520

Armelloni, E.N. et al. (2021) 'AIS data, a mine of information on trawling fleet mobility in the Mediterranean Sea', *Marine Policy*, 129, 104571. https://doi.org/10.1016/j.marpol.2021.104571

Blackburn, T.M. et al. (2011) 'A proposed unified framework for biological invasions', *Trends in Ecology & Evolution*, 26(7), pp. 333–339. https://doi.org/10.1016/j.tree.2011.03.023

Blackburn, T.M. et al. (2014) 'A unified classification of alien species based on the magnitude of their environmental impacts', *PLOS Biology*, 12(5), e1001850. https://doi.org/10.1371/journal.pbio.1001850

Chakravorty, M. et al. (2024) 'A systematic review on the use of food web models for addressing the social and economic consequences of fisheries policies and environmental change', *Frontiers in Marine Science*, 11, 1489984. https://doi.org/10.3389/fmars.2024.1489984

Christidis, G. et al. (2024) 'Another One Bites the Net: Assessing the Economic Impacts of *Lagocephalus sceleratus* on Small-Scale Fisheries in Greece', *Fishes*, 9(3), 104. https://doi.org/10.3390/fishes9030104

Copernicus Marine Service (2026) 'Mediterranean Sea High Resolution and Ultra High Resolution Sea Surface Temperature Analysis' [dataset and product description], Product ID SST_MED_SST_L4_NRT_OBSERVATIONS_010_004. https://doi.org/10.48670/moi-00172

Corrales, X. et al. (2018) 'Future scenarios of marine resources and ecosystem conditions in the Eastern Mediterranean under the impacts of fishing, alien species and sea warming', *Scientific Reports*, 8, 14284. https://doi.org/10.1038/s41598-018-32666-x

D'Amen, M., Smeraldo, S., Di Franco, A. and Azzurro, E. (2022) 'The spread of Lessepsian fish does not track native temperature conditions', *ICES Journal of Marine Science*, 79(6), pp. 1864–1873. https://doi.org/10.1093/icesjms/fsac121

Damalas, D. et al. (2021) 'Evidence of climate-driven regime shifts in the Aegean Sea's demersal resources: A study spanning six decades', *Ecology and Evolution*, 11(23), pp. 16951–16971. https://doi.org/10.1002/ece3.8330

Darmaraki, S. et al. (2019) 'Future evolution of marine heatwaves in the Mediterranean Sea', *Climate Dynamics*, 53, pp. 1371–1392. https://doi.org/10.1007/s00382-019-04661-z

Dayan, H. et al. (2023) 'Marine heat waves in the Mediterranean Sea: an assessment from the surface to the subsurface to meet national needs', *Frontiers in Marine Science*, 10, 1045138. https://doi.org/10.3389/fmars.2023.1045138

Denaxa, D., Korres, G., Darmaraki, S. and Hatzaki, M. (2025) 'Insights into sea surface temperature variability and the impact of long-term warming on marine heatwaves in the Mediterranean Sea', *State Planet*, 6-osr9, 10. https://doi.org/10.5194/sp-6-osr9-10-2025

Digenis, M. et al. (2021) 'New records of the Indo-Pacific shrimp *Urocaridella pulchella* Yokeş & Galil, 2006 from the Eastern Mediterranean Sea', *BioInvasions Records*, 10(2), pp. 295–303. https://doi.org/10.3391/bir.2021.10.2.07

Digenis, M. et al. (2025) 'Assessing the Motile Fauna of Eastern Mediterranean Marine Caves', *Fishes*, 10(8), 383. https://doi.org/10.3390/fishes10080383

Dornelas, M. et al. (2014) 'Assemblage time series reveal biodiversity change but not systematic loss', *Science*, 344(6181), pp. 296–299. https://doi.org/10.1126/science.1248484

European Commission (2000) *Communication from the Commission on the precautionary principle*, COM(2000) 1 final. https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX:52000DC0001

European Commission (2017) *Commission Decision (EU) 2017/848 of 17 May 2017 laying down criteria and methodological standards on good environmental status of marine waters and specifications and standardised methods for monitoring and assessment*. *Official Journal of the European Union*, L 125, 43–74. https://eur-lex.europa.eu/eli/dec/2017/848/oj/eng

European Commission LIFE (2012) 'Concrete Conservation Actions for the Mediterranean Shag and Audouin's Gull in Greece including the inventory of relevant marine IBAs', LIFE07 NAT/GR/000285 [project results]. https://webgate.ec.europa.eu/life/publicWebsite/project/LIFE07-NAT-GR-000285/concrete-conservation-actions-for-the-mediterranean-shag-and-audouins-gull-in-greece-including-the-inventory-of-relevant-marine-ibas

European Parliament and Council (2004) Regulation (EC) No 853/2004 laying down specific hygiene rules for food of animal origin, consolidated text of 18 November 2025, Annex III, Section VIII, Chapter V(E). https://eur-lex.europa.eu/legal-content/EN/TXT/HTML/?uri=CELEX:02004R0853-20251118

European Parliament and Council (2008) *Directive 2008/56/EC establishing a framework for community action in the field of marine environmental policy (Marine Strategy Framework Directive)*. *Official Journal of the European Union*, L 164, 19–40. https://eur-lex.europa.eu/eli/dir/2008/56/oj/eng

European Parliament and Council (2017) *Regulation (EU) 2017/1004 on the establishment of a Union framework for the collection, management and use of data in the fisheries sector*. *Official Journal of the European Union*, L 157, 1–21. https://eur-lex.europa.eu/eli/reg/2017/1004/oj/eng

FAO/GFCM (n.d.) *Data Collection Reference Framework (DCRF)*. General Fisheries Commission for the Mediterranean. Accessed 24 July 2026. https://www.fao.org/gfcm/data/dcrf/en/

Fric, J., Portolou, D., Manolopoulos, A. and Kastritis, T. (2012) *Important Areas for Seabirds in Greece*. LIFE07 NAT/GR/000285. Athens: Hellenic Ornithological Society (HOS/BirdLife Greece), pp. 130–133. https://files.ornithologiki.gr/images/seabirds/Publications/Marine_IBA_Book_BirdLife_Greece_2012_SEC.pdf

Galanidi, M. et al. (2023) 'Validated Inventories of Non-Indigenous Species (NIS) for the Mediterranean Sea as Tools for Regional Policy and Patterns of NIS Spread', *Diversity*, 15(9), 962. https://doi.org/10.3390/d15090962

Galanidi, M., Zenetos, A. and Bacher, S. (2018) 'Assessing the socio-economic impacts of priority marine invasive fishes in the Mediterranean with the newly proposed SEICAT methodology', *Mediterranean Marine Science*, 19(1), pp. 107–123. https://doi.org/10.12681/mms.15940

Garrabou, J. et al. (2022) 'Marine heatwaves drive recurrent mass mortalities in the Mediterranean Sea', *Global Change Biology*, 28(19), pp. 5708–5725. https://doi.org/10.1111/gcb.16301

Garrabou, J., Bensoussan, N. and Azzurro, E. (2018) *Monitoring Climate-Related Responses in Mediterranean Marine Protected Areas and Beyond: Five Standard Protocols*. Barcelona: Institute of Marine Sciences, Spanish Research Council. https://doi.org/10.20350/digitalCSIC/8612

Garrabou, J., Bensoussan, N., Di Franco, A., Boada, J., Cebrian, E., Santamaría, J. et al. (2022) *Monitoring Climate-Related Responses in Mediterranean Marine Protected Areas and Beyond: Eleven Standard Protocols*. Barcelona: Institute of Marine Sciences, Spanish Research Council. https://doi.org/10.20350/digitalCSIC/14672

Giakoumi, S. (2014) 'Distribution patterns of the invasive herbivore *Siganus luridus* and its relation to native benthic communities in the central Aegean Sea', *Marine Ecology*, 35(1), pp. 96–105. https://doi.org/10.1111/maec.12059

Giakoumi, S. and Kokkoris, G.D. (2013) 'Effects of habitat and substrate complexity on shallow sublittoral fish assemblages in the Cyclades Archipelago, North-eastern Mediterranean Sea', *Mediterranean Marine Science*, 14(1), pp. 58–68. https://doi.org/10.12681/mms.318

Giakoumi, S. et al. (2012) 'Relationships between fish, sea urchins and macroalgae: The structure of shallow rocky sublittoral communities in the Cyclades, Eastern Mediterranean', *Estuarine, Coastal and Shelf Science*, 109, pp. 1–10. https://doi.org/10.1016/j.ecss.2011.06.004

Gjoni, V., Garofalo, G., Fiorentino, F., Goerges, V. and Lauria, V. (2026) 'Fishing and warming reshape size spectra of commercial species in the Mediterranean Sea', *Scientific Reports*, advance online publication, 7 July [unedited early-access version]. https://doi.org/10.1038/s41598-026-60738-w

Gobert, S. et al. (2009) 'Assessment of the ecological status of Mediterranean French coastal waters as required by the Water Framework Directive using the *Posidonia oceanica* Rapid Easy Index: PREI', *Marine Pollution Bulletin*, 58(11), 1727–1733. https://doi.org/10.1016/j.marpolbul.2009.06.012

Gomes, R.V.C. et al. (2025) 'The diet and feeding habits of *Lagocephalus sceleratus* in the eastern Mediterranean: A case study carried out off the island of Crete (southern Greece)', *Mediterranean Marine Science*, 26(1), pp. 97–114. https://doi.org/10.12681/mms.38444

Grati, F., Carlson, A., Carpentieri, P. and Cerri, J. (2021) *Handbook for Data Collection on Recreational Fisheries in the Mediterranean and the Black Sea*. FAO Fisheries and Aquaculture Technical Paper No. 669. Rome: FAO. https://doi.org/10.4060/cb5403en

Guarnieri, G., Bevilacqua, S., Figueras, N., Tamburello, L. and Fraschetti, S. (2020) 'Large-scale sea urchin culling drives the reduction of subtidal barren grounds in the Mediterranean Sea', *Frontiers in Marine Science*, 7, 519. https://doi.org/10.3389/fmars.2020.00519

Hamdeno, M. and Alvera-Azcárate, A. (2023) 'Marine heatwaves characteristics in the Mediterranean Sea: Case study the 2019 heatwave events', *Frontiers in Marine Science*, 10, 1093760. https://doi.org/10.3389/fmars.2023.1093760

HCMR/EMODnet (2002) 'Mapping of Natura 2000 site GR4220017—Despotiko and Strongylo' [dataset and metadata]. https://gis.ices.dk/geonetwork/srv/api/records/971255c2-426a-4fbb-a319-3c227dbb0256

Hobday, A.J. et al. (2016) 'A hierarchical approach to defining marine heatwaves', *Progress in Oceanography*, 141, pp. 227–238. https://doi.org/10.1016/j.pocean.2015.12.014

Hoyle, S.D. et al. (2024) 'Catch per unit effort modelling for stock assessment: A summary of good practices', *Fisheries Research*, 269, 106860. https://doi.org/10.1016/j.fishres.2023.106860

Johansen, J.L. et al. (2024) 'Impacts of ocean warming on fish size reductions on the world's hottest coral reefs', *Nature Communications*, 15, 5457. https://doi.org/10.1038/s41467-024-49459-8

Kalloniati, E. et al. (2023) 'Long-term warming and human-induced plankton shifts at a coastal Eastern Mediterranean site', *Scientific Reports*, 13, 21068. https://doi.org/10.1038/s41598-023-48254-7

Kalogirou, S. (2013) 'Ecological characteristics of the invasive pufferfish *Lagocephalus sceleratus* (Gmelin, 1789) in the eastern Mediterranean Sea – a case study from Rhodes', *Mediterranean Marine Science*, 14(2), pp. 251–260. https://doi.org/10.12681/mms.364

Katsanevakis, S. (2011) 'Rapid assessment of the marine alien megabiota in the shallow coastal waters of the Greek islands Paros and Antiparos, Aegean Sea', *Aquatic Invasions*, 6(Suppl. 1), pp. S133–S137. https://doi.org/10.3391/ai.2011.6.S1.030

Katsanevakis, S. et al. (2014) 'Invading the Mediterranean Sea: biodiversity patterns shaped by human activities', *Frontiers in Marine Science*, 1, 32. https://doi.org/10.3389/fmars.2014.00032

Keramidas, I. et al. (2024) 'Temporal ecotrophic impacts of fisheries and climate change in the Aegean Sea', *Marine Ecology Progress Series*, 749, pp. 19–45. https://doi.org/10.3354/meps14724

Keramidas, I., Dimarchopoulou, D. and Tsikliras, A.C. (2022) 'Modelling and assessing the ecosystem of the Aegean Sea, a major hub of the eastern Mediterranean at the intersection of Europe and Asia', *Regional Studies in Marine Science*, 56, 102704. https://doi.org/10.1016/j.rsma.2022.102704

Kleitou, P. et al. (2022) 'Conflicting interests and growing importance of non-indigenous species in commercial and recreational fisheries of the Mediterranean Sea', *Fisheries Management and Ecology*, 29(2), pp. 169–182. https://doi.org/10.1111/fme.12531

Kourantidou, M. et al. (2021) 'Economic costs of invasive alien species in the Mediterranean basin', *NeoBiota*, 67, pp. 427–458. https://doi.org/10.3897/neobiota.67.58926

MacKenzie, D.I. et al. (2002) 'Estimating site occupancy rates when detection probabilities are less than one', *Ecology*, 83(8), 2248–2255. https://doi.org/10.1890/0012-9658(2002)083[2248:ESORWD]2.0.CO;2

Marsaglia, L. et al. (2025) 'Shedding light on trawl fishing activity in the Mediterranean Sea with remote sensing data', *ICES Journal of Marine Science*, 82(2), fsae153. https://doi.org/10.1093/icesjms/fsae153

Minasidis, V. et al. (2023) 'Assessing consumer attitude towards marine non-indigenous fish species: A case study from Greece (Eastern Mediterranean Sea)', *Thalassas*, 39, pp. 35–53. https://doi.org/10.1007/s41208-022-00486-6

Minguito-Frutos, M. et al. (2025) 'Tropical range extending herbivorous fishes gain foraging benefits by shoaling with native temperate species', *Scientific Reports*, 15, 35137. https://doi.org/10.1038/s41598-025-19136-x

Moullec, F. et al. (2019) 'An end-to-end model reveals losers and winners in a warming Mediterranean Sea', *Frontiers in Marine Science*, 6, 345. https://doi.org/10.3389/fmars.2019.00345

Moutopoulos, D.K. et al. (2025) 'Marine Invasive Alien Species Reshape Small-Scale Fisheries: Case Study in Greek Coastal Waters', *Journal of Marine Science and Engineering*, 13(9), 1798. https://doi.org/10.3390/jmse13091798

Munday, P.L. et al. (2008) 'Elevated temperature restricts growth potential of the coral reef fish *Acanthochromis polyacanthus*', *Coral Reefs*, 27(4), pp. 927–931. https://doi.org/10.1007/s00338-008-0393-4

Nikolaou, A. et al. (2023) 'Invasive fish and sea urchins drive the status of canopy forming macroalgae in the Eastern Mediterranean', *Biology*, 12(6), 763. https://doi.org/10.3390/biology12060763

Nuñez, M.A., Kuebbing, S., Dimarco, R.D. and Simberloff, D. (2012) 'Invasive species: to eat or not to eat, that is the question', *Conservation Letters*, 5(5), pp. 334–341. https://doi.org/10.1111/j.1755-263X.2012.00250.x

Oceanus Lab and Vodafone Greece (2024) 'Vodafone Posidonia: Seabed mapping completed in Paros and Antiparos' [research mission report], 18 January. https://www.vodafone.gr/en/digital-press-office/deltia-typou/20240118-vodafone-posidonia-oloklirothike-i-chartografisi-se-paro-kai-antiparo

Ofir, E., de la Puente, S., Corrales, X., Edelist, D., Zemah-Shamir, S., Bitton, G.M., Goffman, O., Sonin, O., Stern, N. and Gal, G. (2026) 'The price of a warming sea: climate change, nonindigenous species, and their impact on Israel's fishing economy', *Frontiers in Marine Science*, 13, 1767110. https://doi.org/10.3389/fmars.2026.1767110

Orfanidis, S., Panayotidis, P. and Ugland, K.I. (2011) 'Ecological Evaluation Index continuous formula (EEI-c) application: a step forward for functional groups, the formula and reference condition values', *Mediterranean Marine Science*, 12(1), pp. 199–232. https://doi.org/10.12681/mms.60

Panayotidis, P. et al. (2022a) 'Seagrass meadows in the Greek Seas: presence, abundance and spatial distribution', *Botanica Marina*, 65(4), pp. 289–299. https://doi.org/10.1515/bot-2022-0011

Panayotidis, P. et al. (2022b) *Seagrass Meadows in The Greek Seas* [dataset]. SEANOE. https://doi.org/10.17882/87740

Pauly, D. (1995) 'Anecdotes and the shifting baseline syndrome of fisheries', *Trends in Ecology & Evolution*, 10(10), p. 430. https://doi.org/10.1016/S0169-5347(00)89171-5

Pecl, G.T. et al. (2017) 'Biodiversity redistribution under climate change: Impacts on ecosystems and human well-being', *Science*, 355(6332), eaai9214. https://doi.org/10.1126/science.aai9214

Person-Le Ruyet, J. et al. (2004) 'Effects of temperature on growth and metabolism in a Mediterranean population of European sea bass, *Dicentrarchus labrax*', *Aquaculture*, 237(1–4), pp. 269–280. https://doi.org/10.1016/j.aquaculture.2004.04.021

Personnic, S. et al. (2014) 'An ecosystem-based approach to assess the status of a Mediterranean ecosystem, the *Posidonia oceanica* seagrass meadow', *PLoS ONE*, 9(6), e98994. https://doi.org/10.1371/journal.pone.0098994

Raitsos, D.E. et al. (2010) 'Global climate change amplifies the entry of tropical species into the Eastern Mediterranean Sea', *Limnology and Oceanography*, 55(4), pp. 1478–1484. https://doi.org/10.4319/lo.2010.55.4.1478

Sáenz-Arroyo, A. et al. (2005) 'Rapidly shifting environmental baselines among fishers of the Gulf of California', *Proceedings of the Royal Society B: Biological Sciences*, 272(1575), pp. 1957–1962. https://doi.org/10.1098/rspb.2005.3175

Sala, E. et al. (2011) 'Alien marine fishes deplete algal biomass in the Eastern Mediterranean', *PLOS ONE*, 6(2), e17356. https://doi.org/10.1371/journal.pone.0017356

Santana-Garcon, J. et al. (2023) 'Tropicalization shifts herbivore pressure from seagrass to rocky reef communities', *Proceedings of the Royal Society B: Biological Sciences*, 290, 20221744. https://doi.org/10.1098/rspb.2022.1744

Savin, A. et al. (2023) 'Assessment of macroalgal communities on shallow rocky reefs in the Aegean Sea indicates an impoverished ecological status', *Mediterranean Marine Science*, 24(2), pp. 241–258. https://doi.org/10.12681/mms.31034

Sini, M. et al. (2019) 'Small-scale coastal fishing shapes the structure of shallow rocky reef fish in the Aegean Sea', *Frontiers in Marine Science*, 6, 599. https://doi.org/10.3389/fmars.2019.00599

Skeeles, M.R. et al. (2023) 'Supplemental oxygen does not improve growth but can enhance reproductive capacity of fish', *Proceedings of the Royal Society B: Biological Sciences*, 290, 20231779. https://doi.org/10.1098/rspb.2023.1779

Stevens, D.L. and Olsen, A.R. (2004) 'Spatially balanced sampling of natural resources', *Journal of the American Statistical Association*, 99(465), 262–278. https://doi.org/10.1198/016214504000000250

Topouzelis, K., Makri, D., Stoupas, N., Papakonstantinou, A. and Katsanevakis, S. (2018) 'Seagrass mapping in Greek territorial waters using Landsat-8 satellite images', *International Journal of Applied Earth Observation and Geoinformation*, 67, pp. 98–113. https://doi.org/10.1016/j.jag.2017.12.013

Touloumis, K. et al. (2025) 'The cascading effect of fishing down marine top predators in the northeastern Mediterranean Sea', *Discover Oceans*, 2, 22. https://doi.org/10.1007/s44289-025-00061-w

Touloumis, K., Dimarchopoulou, D., Koutrakis, M. and Tsikliras, A.C. (2026) 'Greek reconstructed fisheries catches show recession rather than recovery', *Frontiers in Marine Science*, 13, 1766535. https://doi.org/10.3389/fmars.2026.1766535

Tsagarakis, K. et al. (2022) 'Drivers of the North Aegean Sea Ecosystem (Eastern Mediterranean) Through Time: Insights From Multidecadal Retrospective Analysis and Future Simulations', *Frontiers in Marine Science*, 9, 919793. https://doi.org/10.3389/fmars.2022.919793

Tsirintanis, K. et al. (2018) 'Assessment of grazing effects on phytobenthic community structure at shallow rocky reefs: An experimental field study in the North Aegean Sea', *Journal of Experimental Marine Biology and Ecology*, 503, pp. 31–40. https://doi.org/10.1016/j.jembe.2018.01.008

Tsirintanis, K. et al. (2022) 'Bioinvasion impacts on biodiversity, ecosystem services, and human health in the Mediterranean Sea', *Aquatic Invasions*, 17(3), pp. 308–352. https://doi.org/10.3391/ai.2022.17.3.01

Tsirintanis, K. et al. (2023) 'Cumulative negative impacts of invasive alien species on marine ecosystems of the Aegean Sea', *Biology*, 12(7), 933. https://doi.org/10.3390/biology12070933

Tu, C.-Y., Chen, K.-T. and Hsieh, C.-h. (2018) 'Fishing and temperature effects on the size structure of exploited fish stocks', *Scientific Reports*, 8, 7132. https://doi.org/10.1038/s41598-018-25403-x

UNEP/MAP (2016) *Integrated Monitoring and Assessment Programme of the Mediterranean Sea and Coast and Related Assessment Criteria*, Decision IG.22/7. Athens: UNEP/MAP. https://wedocs.unep.org/bitstream/handle/20.500.11822/6090/16ig22_28_22_07_eng.pdf

UNEP/MAP (2021) *Monitoring and Assessment Elements for Non-Indigenous Species*, Appendix E to UNEP/MAP WG.502/16 Rev.1. https://www.rac-spa.org/meetings/nfp15/nfp_docs/appendixes/16/21wg502_16_appendix_e_eng_monitoring_assessment_elements_nis.pdf

van Rijn, I., Buba, Y., DeLong, J., Kiflawi, M. and Belmaker, J. (2017) 'Large but uneven reduction in fish size across species in relation to changing sea temperatures', *Global Change Biology*, 23(9), pp. 3667–3674. https://doi.org/10.1111/gcb.13688

Vergés, A. et al. (2014) 'Tropical rabbitfish and the deforestation of a warming temperate sea', *Journal of Ecology*, 102(6), pp. 1518–1527. https://doi.org/10.1111/1365-2745.12324

Wilkinson, M.D. et al. (2016) 'The FAIR Guiding Principles for scientific data management and stewardship', *Scientific Data*, 3, 160018. https://doi.org/10.1038/sdata.2016.18

Williams, B.K., Szaro, R.C. and Shapiro, C.D. (2009) *Adaptive Management: The U.S. Department of the Interior Technical Guide*. Washington, DC: U.S. Department of the Interior.

Wong, K.L.W. et al. (2026) 'Impacts of invasive rabbitfish species on native herbivore communities in Eastern Aegean coastal ecosystems', *Diversity*, 18(4), 225. https://doi.org/10.3390/d18040225

Wootton, H.F. et al. (2022) 'Smaller adult fish size in warmer water is not explained by elevated metabolism', *Ecology Letters*, 25(5), pp. 1177–1188. https://doi.org/10.1111/ele.13989

Yeruham, E. et al. (2015) 'Collapse of the echinoid *Paracentrotus lividus* populations in the Eastern Mediterranean—result of climate change?', *Scientific Reports*, 5, 13479. https://doi.org/10.1038/srep13479

Zampoukas, N. et al. (2014) *Technical Guidance on Monitoring for the Marine Strategy Framework Directive*. EUR 26499 EN. Luxembourg: Publications Office of the European Union. https://doi.org/10.2788/70344

Zenetos, A. et al. (2015) 'ELNAIS: A collaborative network on Aquatic Alien Species in Hellas (Greece)', *Management of Biological Invasions*, 6(2), 185–196. https://doi.org/10.3391/mbi.2015.6.2.09

Zenetos, A. et al. (2022) 'Established non-indigenous species increased by 40% in 11 years in the Mediterranean Sea', *Mediterranean Marine Science*, 23(1), pp. 196–212. https://doi.org/10.12681/mms.29106. Corrigendum: https://doi.org/10.12681/mms.31523

Zenetos, A. et al. (2025) 'Non-Indigenous Species (NIS) Know No Geopolitical Borders—An Update of NIS in the Aegean Sea', *Diversity*, 17(1), 12. https://doi.org/10.3390/d17010012

Υπουργείο Αγροτικής Ανάπτυξης και Τροφίμων (ΥΠΑΑΤ) (2026) 'Το ΥΠΑΑΤ ενεργοποιεί το πιλοτικό πρόγραμμα διαχείρισης του λαγοκέφαλου—Δημόσια δαπάνη 1,5 εκατ. ευρώ για Κρήτη και Νότιο Αιγαίο—Αμοιβή έως 5,33 ευρώ ανά κιλό για τη στοχευμένη αλίευση από επαγγελματίες αλιείς', 29 June. https://www.minagric.gr/2013-04-05-10-13-09/ministry-example/ypaat-grafeio-typou/deltiatypou/19591-dt290626

About the Author

Bill (Βασίλης) Marangozis is an independent researcher and a retired business executive with more than four decades of experience in the printing and publishing industries. He is a former editor of *The Brighton Beacon*. Trained in mathematics, with long-standing interests in physics, ocean science and climate change, he has maintained a close personal relationship with Paros since childhood and has observed its coastal and marine environment over several decades. *The Mediterranean in Transition / Η Μεσόγειος που αλλάζει* forms part of his independent, evidence-led work on the ecological and socioeconomic future of the Aegean and the Cyclades.