Context

In the Indo-Pacific Ocean, the biodiversity of rivers on volcanic islands relies primarily on amphidromous species. Among these, **the endemic gobies**[1] *Cotylopus acutipinnis* (Mascarene Archipelago, Indian Ocean), *C. rubripinnis* (Comoros Archipelago, Indian Ocean), and *Sicyopterus pugnans* (Polynesia, Pacific Ocean) coexist sympatrically with the widely distributed goby *Sicyopterus lagocephalus* (Pacific and Indian Oceans). These species, locally significant in ecological and economic terms, exhibit an amphidromous life cycle. Adults reproduce in rivers, and their eggs hatch into prolarvae that descend to the sea in few hours. In the marine environment, they develop into marine larvae, carried by currents for several months before returning to islands where they colonise rivers as post-larvae during the recruitment stage. They then undergo metamorphosis into juveniles, growing in rivers until reaching the reproductive adult stage. When they return to the rivers, post-larvae are targeted by traditional fishing practices at river mouths, with pressure levels varying between islands.

In the Indo-Pacific tropical regions, island river ecosystems consist mainly of young oligotrophic rivers with alternating flow intensities depending on wet and dry seasons. Amphidromous species have a reservoir of larvae at sea, protected from climatic variations associated with rivers, enabling them to naturally recolonise rivers after dry periods, when environmental conditions become favourable again. This particularity explains why amphidromous species constitute the majority of biodiversity in these freshwater environments: only they are capable of naturally recolonizing river systems. The persistence of these species at the island and/or regional scale depends on exchanges between spawning areas in rivers and growth areas at sea, occurring during the dispersive larval stage—the only stage capable of ensuring connectivity between distant populations (within an archipelago for endemic species or between archipelagos for the widely distributed species). During their marine growth phase, these planktonic larvae undergo stochastic/turbulent processes inherent to the marine environment they disperse in, for several weeks to months, before returning to colonise rivers. Environmental stochasticity induces variability in larval recruitment, in terms of abundance, age, weight, size, and condition index (i.e., life history traits or LHT), at recruitment.

Within different archipelagos, the sympatric presence of each endemic species with the widely distributed species, all characterised by the same amphidromous life cycle, raises questions about the determinants of endemism. Since these species share a dispersive larval phase at sea, a plausible hypothesis is that the life history traits of endemic species (e.g., spawning period, duration of larval phase at sea, vertical behaviour in the water column during dispersion) favour their retention near islands, while those characterising the widely distributed species are compatible with dispersion to open waters, allowing connections with other archipelagos. Studying and comparing the life history traits of different species, based on their geographical distribution at juvenile and adult stages and over time, is therefore essential to provide the first clues. However, this approach seems insufficient if not accompanied by elucidating the ocean migration trajectories of larvae of the different species, based on spawning dates and the rivers they are emitted from. The use of hydrodynamic and Lagrangian dispersion models will estimate the probable trajectories of these planktonic larvae, as they depend on currents. Nevertheless, modelling remains a probabilistic approach that needs consolidation with data from the analysis of otoliths of larvae, considering that otoliths integrate elements from the environment traversed by individuals. A micro-scale chemical analysis of otoliths will identify, among the possible migration trajectories revealed by the modelling approach, those most realistic based on elements integrated into the otoliths of sampled fish.

Moreover, the species targeted by our study are vulnerable to various anthropogenic pressures (river pollution, fishing, habitat fragmentation due to river dams, ocean warming and acidification, precipitation regime changes) or natural pressures (climate variability modes, volcanism), which could weaken stocks and compromise the persistence of these species, particularly the endemics. It is

[1] gobies are teleosts (Teleostei : Gobiidae : Sicydiinae)

therefore crucial to study and understand the dynamics of these populations with such complex life cycles to envisage effective protection measures for these important species at the core of the socio-ecosystems of many tropical volcanic islands.

Scientific Objectives of the Project

The thesis project is structured around three axes, relying on interdisciplinary approaches and innovative, original techniques. These three axes aim together to elucidate the dynamics of goby populations in the Indo-Pacific and compare them among endemic species from different regions and with the widely distributed species. The origin of post-larvae recruiting in the rivers of the three islands where juveniles and adults of endemic amphidromous gobies coexist with the widely distributed species, will also be determined. This will allow proposing effective management plans for these species whose sustainability is not assured. This interdisciplinary study comprises **an ecology axis**, **a hydrodynamic modelling axis**, and an **analysis of the chemical composition of otoliths at the sub-micrometric scale**.

1st Axis: Spatio-temporal variability of post-larvae traits at recruitment (supervised by Céline Ellien; co-supervised by Ibrahim Yahaya, CNDRS, Comoros Republic)

Through this axis, we will study and compare the life history traits (LHT) of post-larvae of the four amphidromous goby species, among the three islands and the two seasons (summer and austral winter). The objective is to determine if the LHT of post-larvae of endemic species are comparable between regions where they are found (i.e., between species) and if they differ from the characteristics of the widely distributed species (*S. lagocephalus*). Similarly, we will investigate if the LHT of *S. lagocephalus* are homogeneous across its distribution range, or if plasticity can be demonstrated, relative to different regional environmental conditions (ocean temperature, food resource, etc.). For a given species, we will check if LHT varies spatially on a small scale, depending on the location of rivers on either side of the islands. Rivers are selected based on their geographical location on the windward or leeward coast, with the leeward coast characterised by a drier climate than the windward coast. This will provide an initial answer to whether post-larval traits vary depending on shore facies. Sampling will be conducted seasonally in Mohéli (Comoros Archipelago) as part of a collaboration with CNDRS (National Centre for Documentation and Scientific Research of Comoros). In Reunion island, post-larvae of the two goby species will be provided monthly by the Observatory of Migratory Flows (DYNAPOP project, in which the thesis director is involved). In Tahiti, monthly river sampling will be carried out as part of the "Ina'a" project (title: The fishing of gobiid post-larvae in French Polynesia: the case of the ina'a fishery on the island of Tahiti), also involving the thesis director. Each sample will consist of 50 individuals, which will be measured and weighed. Their age will be estimated by otolithometry: knowing that the nucleus is already present in the egg, the number of growth rings indicates the age of the post-larva at the time of capture, and thus the duration of its marine dispersion (PLD).

2nd Axis: Hydrodynamical modelling (supervised by Xavier Capet and Stéphane Pous)

During their marine phase, planktonic larvae are driven by ocean currents that influence the population structure and dynamics of these specific species. A hydrodynamic modelling study, incorporating the spawning date estimated by otolithometry and the recruitment location (i.e., rivers where post-larvae were sampled), will help identify potential migration trajectories based on the currents and other physical forcings experienced by the larvae along their path. For this axis, we will utilize the oceanic reanalysis GLORYS, derived from the NEMO model, providing a time series of oceanic properties. To model larval dispersion, the individual-centered model ICHTHYOP will be employed to calculate probable migration trajectories based on the results of the GLORYS reanalysis.

This Lagrangian model serves as a relevant and powerful tool to verify hypotheses regarding the population structure of *S. lagocephalus* as a metapopulation and to identify source and sink populations at the scale of an oceanic basin. This modelling tool will allow, on the one hand, to determine the potential geographical origin of post-larvae, a crucial preliminary step for developing suitable conservation plans, and on the other hand, to assess the extent to which larvae disperse offshore or remain in coastal areas, contributing to explaining the cosmopolitanism vs. endemism of the target species. Through this approach, we can also quantify the relative importance of meteorological forcings and biotic factors (spawning dates and locations, duration of the larval phase, amplitude of nycthemeral migrations) on larval dispersion.

3rd Axis: Sub-micrometric scale analysis of the chemical composition of otoliths (supervised by Cédric Baumier)

This axis aims to determine the elemental composition of otoliths, from the nucleus to the periphery, always with the aim of elucidating the geographical origin of post-larvae and their migration routes. Using scanning and transmission electron microscopes, each equipped with EDX detectors (Bacri et al., 2017), we will be able to map the otolith, indicating how different constituent elements are distributed in this biomineral structure at micro and nano-metric scales. This method should provide insights into the life history of individuals, as well as the elements that teleosts extract and incorporate into their bio-mineral structures. Formed in the egg, the nucleus incorporates elements from its original river. By comparing the elements identified in this part of the otolith with the elemental composition and trace elements of island rivers, during both seasons, we will determine where the sampled post-larvae were spawned. As for the composition of growth rings, it will shed light on possible larval migration routes and confirm or refute those predicted by the hydrodynamic model, for example, distinguishing between offshore dispersion of larvae or, conversely, a larval phase that remains close to the coast, leaving larvae in a mixed influence of freshwater and seawater. Micro-scale analyses of otoliths have already proven their relevance in studying the life history of teleost fish (Laugier et al., 2015). We are confident that the electron microscopy approach with EDX detectors, spatially better resolved than commonly used techniques, will represent a major advancement in this type of ecological study.

This doctoral research project fits well within the call for proposals of the Initiative Biodiversité, Evolution, Ecologie, Société, as it focuses on species whose presence in rivers constitutes the essence of freshwater biodiversity. However, these species face various pressures jeopardizing their local persistence, especially the endemic ones. These species also hold a significant place in island societies, placing them at the heart of an important but fragile socio-ecosystem. In this regard, it is crucial to better understand the dynamics of these species to effectively protect them in the long term. To achieve this, we envisage an innovative multidisciplinary approach that resonates with the requirements of this call.

ANNEXES

Supervision Modalities

The thesis will be co-supervised by physicists and modelling researchers from UMR LOCEAN (Stéphane Pous and Xavier Capet) for 15%, and by a research engineer in chemistry, responsible for the SCALP platform (CNRS, Orsay campus) for 15%. The thesis director will supervise 70% of the work. The doctoral work will take place partly in Paris (UMR BOREA and UMR LOCEAN) and partly in Orsay. A thesis monitoring committee will also be set up to provide an external perspective on the doctoral student's work, with three meetings planned during the thesis.

Feasibility

Post-larvae will be collected monthly at river mouths: 1) in Reunion Island as part of the DYNAPOP project, funded for 3 years and renewable, and 2) at the mouths of Tahitian rivers as part of the Ina'a project, funded for 2 years and renewable. Regarding samplings at the mouths of rivers in Mohéli (Comoros), occasional funding (AAP UMR BOREA, ATM MNHN) will be requested to finance seasonal collection campaigns (2 collections per year). A collaboration with CNDRS in the Comoros (CNDRS/UMR BOREA (BIOPAC team) within a broader CNDRS/MNHN Paris agreement) has been structured in 2022 and is now stabilized. A first sampling mission was conducted in May 2023 in Mohéli rivers. The Ocea Consult study office finances 50% of the costs related to samplings in the Comoros from its own resources. This study office also performs samplings in Reunion Island. The Ichthyo-Pacific study office samples Tahitian rivers. These two study offices are partners in the listed scientific projects. The candidate will not have a field mission to carry out. Therefore, the project is undoubtedly feasible within the allotted time.

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Candidate Profile

We will select a candidate with knowledge in ecology and marine environments, particularly hydrodynamic forcings. The candidate should demonstrate skills in statistical data analysis. Otolithometry skills will be an additional asset but are not essential. The candidate should show interest in physico-chemical analyses and microscopy. Adaptability and open-mindedness are essential qualities, given the interdisciplinary nature of the topic. Masters programs that can prepare students to apply for this topic include Biodiversity Evolution Ecology (BEE), Marine Sciences (SdM), Tropimundo, or Oceanian Insular Environment (EIO). We prefer a candidate trained in ecology rather than physics or chemistry, even though this project could be led by a physicist experienced in modelling and programming techniques or a chemist with a background in material chemistry or physical chemistry.

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