



Think global to act local: an interdisciplinary evaluation of the restocking of Northern temperate eel species (*Anguilla* spp.) as a conservation action

Hermione Froehlicher

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**THÈSE PRÉSENTÉE POUR OBTENIR LE GRADE DE
DOCTEUR DE**

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ÉCOLE DOCTORALE EES

SPÉCIALITÉ SCIENCES ECONOMIQUES

Par Hermione FROEHLICHER

**PENSER GLOBAL POUR AGIR LOCAL : UNE EVALUATION
INTERDISCIPLINAIRE DU REPEUPLEMENT DES ESPECES
D'ANGUILLES TEMPEREES DU NORD (*ANGUILLA* SPP.) COMME
ACTION DE CONSERVATION**

**Think global to act local: an interdisciplinary evaluation of the restocking of
Northern temperate eel species (*Anguilla* spp.) as a conservation action**

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Soutenue le 05/12/2023

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Titre : Penser global pour agir local : une évaluation interdisciplinaire du repeuplement des espèces d'anguilles tempérées du Nord (*Anguilla spp.*) comme action de conservation

Résumé : La conservation de la biodiversité représente un défi majeur de l'Anthropocène, ère durant laquelle les effets du changement climatique et de la dégradation des habitats se manifestent au sein d'une économie mondialisée et d'un contexte de montée des consciences écologiques. Les poissons migrateurs amphihalins sont particulièrement touchés par la crise d'extinction de la biodiversité. Ces espèces évoluent dans des milieux aquatiques variés, ce qui les expose à d'autant plus de difficultés. Les espèces d'anguilles (*Anguilla spp.*) en sont un exemple emblématique, notamment les espèces tempérées de l'hémisphère Nord. L'anguille européenne (*Anguilla anguilla*) a été la première à voir sa population chuter et elle est aujourd'hui classée comme espèce en danger critique d'extinction par l'UICN. Cette thèse a pour objectif d'évaluer l'efficacité d'une mesure spécifique de conservation sur ces espèces : le repeuplement. Une approche interdisciplinaire par le biais du cadre d'analyse des systèmes socio-écologiques y est mobilisée. Dans un premier axe, une revue de la littérature scientifique avec une méthodologie mixte de revue systématique et revue narrative a été réalisée, afin de faire l'état des connaissances sur l'efficacité écologique du repeuplement de l'anguille comme action de conservation en lien avec les processus biologiques et écologiques. Cette revue met en lumière le manque de cohérence écologique pour les perspectives de conservation d'une telle mesure. Dans un second axe, la régulation de la consommation a été étudiée, en partant du principe qu'une réduction de la demande était nécessaire afin d'atteindre les objectifs de conservation et d'utilisation durable de la ressource. Une évaluation des préférences des consommateurs historiques de l'anguille, les japonais, en matière de politiques de gestion visant à la conservation des anguilles a été réalisée. La méthode des expériences de choix discrets nous a permis de distinguer trois classes parmi les consommateurs d'anguille japonais en fonction de leurs caractéristiques, de leur niveau de sensibilité environnementale et des types de politiques de gestion qu'ils voulaient favoriser. Dans un troisième axe, l'objectif a été de comprendre l'efficacité du repeuplement en tant que système socio-écologique (SES) impliquant des interactions entre des facteurs écologiques, socio-économiques et institutionnels. Le cas d'étude de la pêcherie de civelles (juvénile de l'anguille) dans l'Unité de Gestion de la Loire, Côtiers vendéens et Sèvre niortaise en France a été choisi. Nous avons caractérisé ce territoire de gestion comme un SES en identifiant un ensemble de variables et reconstruit les interactions entre ces variables en nous basant sur la littérature existante et les résultats d'une enquête menée auprès des pêcheurs professionnels de la zone étudiée. Une modélisation qualitative de boucle a permis d'identifier des scénarios qui semblent viables à la fois sur le plan écologiques et socio-économiques, tous impliquant la mise en œuvre de mesures visant à réduire la pression de la pêche sur la ressource en civelles. Cependant, il est essentiel d'évaluer de manière critique les implications de ces scénarios, en particulier lorsqu'ils entraînent un report de l'effort de pêche sur des espèces complémentaires pouvant également être soumises à de fortes pressions. D'autres scénarios impliquant les niveaux de capture et les revenus des pêcheurs ne semblent pas avoir d'effets concluants. Les résultats de cette thèse montrent que le repeuplement seul n'est pas une mesure de gestion suffisante pour reconstituer les populations d'anguilles. Des mesures de régulation de la demande sont nécessaires et attendues et la mise en place d'outils complémentaires de gestion visant à réduire l'effort de pêche sur la civelle pourrait permettre d'atteindre le double objectif de la conservation et de l'utilisation durable des anguilles en tant que ressources halieutiques.

Mots-clés : Conservation de la biodiversité, Interdisciplinarité, Systèmes socio-écologiques, *Anguilla spp.*

Title: Think global to act local: an interdisciplinary evaluation of the restocking of Northern temperate eel species (*Anguilla spp.*) as a conservation action

Abstract: Biodiversity conservation at the age of Anthropocene is a central concern. The erosion of biodiversity is not only specifically the concern of ecology but also of society and economy, where impacts of global warming and habitat degradation occur in a globalized economy network and a rise of ecological consciousness worldwide. Migratory amphihaline fish are particularly hard hit by the current biodiversity extinction crisis. These species live in a variety of aquatic environments, which makes them all the more vulnerable. Eel species (*Anguilla spp.*) are an emblematic example, particularly temperate species in the northern hemisphere. The European eel (*Anguilla anguilla*) was the first to see its population decline and is now classified as Critically Endangered by the IUCN. The aim of this thesis is to assess the effectiveness of a specific conservation measure on these species: restocking. It uses an interdisciplinary approach based on the framework of socio-ecological systems. Firstly, a review of the scientific literature was carried out using a mixed methodology of systematic review and narrative review, in order to assess the state of knowledge on the ecological efficiency of eel restocking as a conservation action in relation to biological and ecological processes. This review highlights the lack of ecological consistency for the conservation prospects of such a measure. Secondly, the regulation of consumption was studied, based on the assumption that a reduction in demand was necessary in order to achieve the objectives of conservation and sustainable use of the resource. An assessment of the preferences of the historical consumers of eel, the Japanese, in terms of management policies aimed at eel conservation was carried out. The method of discrete choice experiments enabled us to distinguish three classes among Japanese eel consumers according to their characteristics, their level of environmental sensitivity and the types of management policies they wanted to favor. The third axis of the thesis aimed at understanding the efficiency of restocking as a socio-ecological system (SES) involving interactions between ecological, socio-economic and institutional factors. The case study of the glass eel fishery (juvenile eels) in the Loire, Côtiers vendéens and Sèvre niortaise Management Unit in France was chosen. We characterized this management area as an SES by identifying a set of variables and reconstructing the interactions between these variables on the basis of existing literature and the results of a survey of professional fishermen in the study area. Qualitative loop modelling was used to identify scenarios that appear to be ecologically and socio-economically viable, all involving the implementation of measures aimed at reducing fishing pressure on glass eel resources. However, it is essential to critically assess the implications of these scenarios, particularly when they involve shifting fishing effort onto complementary species that are also under heavy pressure. Other scenarios involving catch levels and fishermen's incomes do not seem to have conclusive effects. The results of this thesis show that restocking alone is not a sufficient management measure to rebuild eel populations. Measures to regulate demand are necessary and expected, and the introduction of complementary management tools aimed at reducing the fishing effort on glass eels could make it possible to achieve the dual objective of conservation and sustainable use of eels as a fishery resource.

Keywords: Biodiversity conservation, Interdisciplinarity, Socio-ecological systems, *Anguilla spp.*

Unités de recherche

UR INRAe, ETTIS (Environnement, Territoires en Transition, Infrastructures, Sociétés) et EABX (Ecosystèmes aquatiques et changements globaux), 50 Avenue de Verdun, 33612 Cestas Cedex

Résumé substantiel

Le consensus scientifique a établi que la biodiversité est en rapide déclin et que la planète connaît actuellement sa sixième extinction de masse. Cette diminution des espèces est particulièrement grave dans les écosystèmes d'eau douce et estuariens, qui abritent un quart de toutes les espèces de vertébrés et plus de la moitié des espèces de poissons. Aujourd'hui, près d'un tiers des espèces de poissons d'eau douce sont menacées d'extinction. Parmi elles, les poissons migrateurs amphihalins sont particulièrement touchés, car ils cumulent les difficultés rencontrées dans différents types d'habitats. L'abondance de poissons migrateurs emblématiques tels que le saumon et l'anguille a diminué de plus de 75 % au cours des 50 dernières années. Certaines populations, comme celles des anguilles tempérées de l'hémisphère Nord (*Anguilla* spp.) qui sont au centre de cette thèse, sont classées par l'UICN comme étant en danger d'extinction (l'anguille d'Amérique *Anguilla rostrata* et l'anguille japonaise *Anguilla japonica*) voire même en danger critique d'extinction (l'anguille européenne *Anguilla anguilla*). Les plus fortes baisses de l'abondance de ces espèces ont été observées entre 1980 et 2010, en commençant par l'anguille européenne. Leur recrutement est resté à des niveaux relativement bas après cette période. Les espèces d'anguilles tempérées de l'hémisphère Nord sont des espèces catadromes facultatives, qui se reproduisent dans l'océan et migrent vers les habitats d'eau douce et saumâtre pour effectuer leur croissance et développer leur appareil reproducteur, avant de migrer à nouveau vers l'océan dans le but de se reproduire. En tant qu'espèces semelpares, les anguilles n'effectuent ce cycle qu'une seule fois avant de mourir. Le déclin de l'abondance des espèces d'anguilles est probablement le résultat de l'effet cumulatif de la surpêche et de multiples pressions anthropiques (barrières migratoires, perte et altération des habitats, pollution) sur leur environnement aquatique. Dans l'Union européenne, l'une des réalisations notables en matière de gestion est le Règlement du Conseil européen (n° 1100/2007 publié en septembre 2007) qui impose à tous les États Membres dans lesquels l'anguille européenne est présente, d'établir des plans de gestion visant à la conservation de l'espèce. L'objectif est de permettre l'échappement d'au moins 40 % de la biomasse des anguilles argentées vers la mer, par rapport aux niveaux estimés de la population d'origine. Le repeuplement est indiqué dans le règlement comme mesure afin d'atteindre cet objectif d'échappement et d'augmenter les captures de pêche. Les bienfaits du repeuplement sont prônés depuis le milieu du 19^e siècle, mais restent très controversés. Au sein des États Membres européens soumis à la réglementation sur l'anguille, seuls 21 % des civelles sont officiellement échangées en vue du repeuplement.

L'objectif principal de cette thèse est d'**évaluer l'efficacité du repeuplement en tant que mesure de conservation des espèces d'anguilles** en adoptant une perspective de système socio-écologique dans le cadre d'une approche interdisciplinaire. Cette pensée socio-écologique reconnaît le repeuplement comme une interaction complexe entre l'homme et la nature englobant des processus écologiques, des processus socio-économiques et leurs interactions. Nous avons élaboré une compréhension approfondie de l'(in)efficacité des **interactions socio-écologiques** dans le repeuplement en suivant trois axes de recherche complémentaires.

Dans le **premier axe** (chapitre 1), nous avons identifié dans la littérature scientifique quelles étaient les interactions biologiques et écologiques qui influencent l'efficacité du repeuplement comme action de conservation des anguilles. Le repeuplement est alors englobé dans un ensemble de mesure que l'on appelle les actions de translocation, qui peuvent suivre différentes approches, en fonction des objectifs et du contexte. L'évaluation des résultats des projets de translocation visant à restaurer les populations d'anguilles est complexe, principalement parce que la dernière partie de son cycle de vie, la reproduction, est mal connue et n'a jamais été observée dans la nature. Nous nous sommes donc concentré sur la phase océanique du cycle de vie de l'anguille, et avons combiné une approche systématique et narrative. Nous avons dans un premier temps constitué une base de données de 956 articles publiés entre 1933 et 2021, à laquelle nous avons appliqué une analyse automatisée du contenu afin d'identifier les principales controverses au sujet de l'effet de la translocation sur les processus biologiques et écologiques des anguilles. Les principaux thèmes associés à la translocation étaient la survie, la migration et la sélection par l'environnement. Ces thèmes ont été analysés plus en détail dans le cadre d'une revue narrative sur la base d'une sélection d'articles récents. La revue a révélé que, d'une part, il existe un consensus sur le fait que la translocation interagit avec les processus de sélection naturelle (incompatibilité phénotype/environnement) et que, d'autre part, les anguilles transloquées migrent belle et bien vers la zone de reproduction en tant qu'anguilles argentées. Cependant, il subsiste des lacunes de recherche sur la comparaison de la survie des anguilles transloquées et des anguilles sauvages. Un thème émergent était l'effet de la translocation des anguilles à l'échelle de la communauté. Sur la base des résultats de la revue, les futures recherches devront se concentrer sur la comparaison directe de l'écologie des anguilles transloquées et de leurs homologues sauvages dans l'environnement naturel, ainsi que sur l'étude de l'impact des actions de translocation au niveau de la communauté.

Pour atteindre le double objectif de la conservation de la biodiversité et de l'utilisation durable des ressources halieutiques, il est nécessaire de réduire la demande des consommateurs d'anguilles. Cependant, on sait relativement peu de choses sur les préférences des

consommateurs en matière d'adoption de réglementations spécifiques. Le principal objectif du **deuxième axe** (chapitre 2) est de contribuer à ce sujet. Nous avons mené une étude quantitative afin d'évaluer les préférences des consommateurs historiques de l'anguille, soient les japonais, en matière de politiques de gestion visant à la conservation des anguilles. En effet, ces dernières sont une ressource alimentaire importante au Japon et constituent une référence de la cuisine japonaise, et cela malgré le déclin du stock d'anguilles local, *Anguilla japonica*. Les anguilles consommées au Japon proviennent de trois sources : la pêche, l'élevage *i.e. le grossissement puisque la reproduction artificielle n'est pas réalisable à large échelle* et l'importation d'anguilles vivantes provenant d'autres pays asiatiques. En utilisant une expérience de choix discret, l'objectif de cette recherche est d'analyser les préférences et les compromis faits par les individus concernant différents leviers de politique pour la conservation des anguilles au Japon (par exemple, la régulation directe de la consommation, la promotion d'espèces de substitution, les politiques basées sur les prix, le développement de la recherche sur l'aquaculture et la reproduction artificielle des anguilles, les politiques basées sur l'information, la lutte contre le commerce illégal d'anguilles en contrôlant les importations). La situation actuelle a servi de scénario de référence. En particulier, nous avons tenu compte de la sensibilité environnementale et de l'engagement individuel, du niveau de revenu, de l'âge et de la localisation (rurale versus urbaine) dans un modèle à trois classes latentes. Un échantillon de 1088 individus a été utilisé. Les résultats montrent que les consommateurs à faible revenu et moins sensibles aux questions environnementales préfèrent fortement l'alternative du statu quo. En revanche, les consommateurs avec une conscience environnementale plus accrue ont une forte préférence pour une régulation plus stricte du marché, soutenant les politiques basées sur les prix.

Sur la base des résultats obtenus dans le premier chapitre, nous pouvons affirmer que le repeuplement seul n'est pas une mesure de gestion suffisante pour reconstituer la population d'anguilles. Afin de conserver et d'utiliser durablement les anguilles, des mesures de régulation de la demande sont nécessaires et attendues, comme le montrent les résultats du second axe. L'objectif du **troisième axe** de la thèse (chapitre 3) est donc de comprendre l'efficacité du repeuplement en tant que système socio-écologique (SES) impliquant des interactions entre des facteurs écologiques, socio-économiques et institutionnels. Nous avons appliqué ce cadre d'analyse afin d'explorer les problèmes liés à la gestion de la pêcherie de civelles *i.e. les juvéniles de l'anguille* dans l'Unité de Gestion de l'Anguille (UGA) Loire, Côtiers vendéens et Sèvre niortaise (LCV) en France. La France est le seul pays qui dispose d'un système de quotas de pêche pour la civelle, qui permet de prioriser les projets de repeuplement par rapport à la consommation. L'UGA LCV est particulièrement intéressante car elle concentre une grande

partie des captures de civelles en Europe. Nous avons caractérisé ce territoire de gestion comme un SES en utilisant un ensemble de variables. Nous avons reconstruit les interactions entre ces variables en nous basant sur la littérature existante et les résultats d'une enquête menée auprès des pêcheurs professionnels de l'UGA étudiée. Nous avons utilisé une modélisation qualitative de boucle qui exploite la structure de ces interactions afin d'identifier les trajectoires responsables de la propagation des impacts et des rétroactions qui modulent les effets des différentes mesures de gestion (qui complèteraient le repeuplement des anguilles) sur l'effort de pêche, le niveau des stocks et le revenu des pêcheurs, en avançant ainsi vers une gestion écosystémique de la pêche à la civelle. Nous avons testé les effets d'une baisse de quota pour le marché de la consommation, mais aussi les effets de la régulation de l'effort de pêche ou du report de cet effort de pêche sur des espèces complémentaires/accompagnatrices. Nous avons finalement testé l'effet de deux instruments basés sur les prix (prix subventionné pour le secteur du repeuplement ou taxe supplémentaire pour le secteur de la consommation). La modélisation a permis d'identifier des scénarios qui semblent écologiquement et socio-économiquement viables, tous impliquant la mise en œuvre de mesures visant à réduire la pression de pêche sur la ressource en civelles. Cependant, il est essentiel d'évaluer de manière critique les implications de ces scénarios, en particulier lorsqu'ils impliquent de reporter l'effort de pêche sur des espèces complémentaires qui peuvent également être soumises à de fortes pressions. En outre, le contexte plus large des restrictions autour de la pêche à la civelle ne semble pas permettre la mise en place de pratiques de pêche durables.

Par le biais d'une approche interdisciplinaire, cette thèse a permis de proposer et d'approfondir des approches différentes de celles utilisées classiquement pour faire de l'évaluation de mesure de conservation. Les résultats démontrent que des méthodes plus qualitatives et moins dépendantes du nombre de données permettent de compléter les méthodes quantitatives et d'apporter des pistes de réflexion plus globales, comme ici sur l'utilité du maintien d'une économie de la civelle en France et l'émergence de préoccupations environnementales chez les consommateurs d'espèces menacées.

A ma grand-mère.
J'aurais tant aimé que nous partagions ce moment...

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I'm going to switch in English for this one, because it was impossible for me not to thank the person who, not only helped me so much throughout the thesis contributing to the writing, but also gave me a royal welcome in Tokyo when I came here on last May: Kenzo, from the bottom of my heart, thank you! どうもありがとうございます。

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Contents

Résumé substantiel	4
Remerciements	9
List of figures	13
List of tables	14
List of supplementary material.....	15
List of abbreviations	16
Introduction	17
Foreword: Biodiversity conservation in a context of global change	18
The global collapse of biodiversity	18
The great deal of biodiversity conservation	19
The need for interdisciplinarity to address the environmental issue of biodiversity conservation	20
General introduction:	22
1. The case study of Northern temperate Anguillid eel species conservation	22
1.1. Migratory fish as emblematic examples of biodiversity collapse	22
1.2. The complexity of Northern temperate eels' species life cycle makes them particularly vulnerable to anthropogenic threats.....	23
1.3. The fragility of Northern temperate eel species is exacerbated by their high economical value	25
1.4. Restocking of Northern temperate eel species: between conservation and exploitation	28
2. The framework of Socio-Ecological systems and use of mixt methods to understand and evaluate the efficiency of eel restocking	30
2.1. Objective of the thesis.....	30
2.2. First research axis	31
2.3. Second research axis	32
2.4. Third research axis.....	33
2.5. Interdisciplinarity in thesis: a unique experience	35
First chapter_Eel translocation from a conservation perspective: a coupled systematic and narrative review	38
Abstract.....	39
1. Introduction.....	40
2. Materiel and method	43
2.1. Conceptual background and review framework.....	43
2.2. Literature search and selection.....	44
2.3. Synthetic review with automated content analysis.....	45
2.4. A comprehensive narrative review method.....	46

3. Results.....	47
3.1. Content analysis	47
3.1.1. Bibliometric	48
3.1.2. Major research streams	51
3.1.3. Key themes and representative articles	52
3.2. Insights from narrative review	52
3.2.1. The growth and survival of translocated eels compared to wild eels	52
3.2.2. A mismatch between phenotype and habitats	52
3.2.3. Translocated eels' migration capacity compared to wild eels	53
3.2.4. The impact of translocation on recipient ecosystems.....	54
4. Discussion and conclusion.....	54
4.1. Implications for research.....	56
4.2. Implications for conservation policy making	59

Second chapter_Conserving threatened eel species with policy instrument mixes in

Japan: what's consumers' pro-environmental orientation got to do with it? 62

Abstract.....	63
1. Introduction.....	64
2. The Japanese context	67
3. Choice design and data collection	68
3.1. Policy scenarios' attributes	69
3.2. Choice experiment design	72
3.3. Data collection and survey design	75
3.4. Sample characteristics	76
4. Econometric analysis	79
4.1. Econometric modelling framework	79
4.2. Source of heterogeneity	81
4.3. Testing the impact on preferences of information about the eel trade	83
4.4. Latent class logit modelling	88
5. Discussion and policy implications	94

Third chapter_French connections: a socio-ecological system modelling approach for the restocking of European eel 97

Abstract.....	98
1. Introduction.....	99
2. From restocking to ecosystem-based management	102
3. Material and methods	104
3.1. SES around restocking in France.....	104
3.2. Qualitative loop modelling	110

3.3. Management scenario testing	113
4. Results.....	115
4.1. Model consistency and validity	115
4.2. Predicted outcomes of management actions.....	118
4.3. Sensitivity analysis.....	121
5. Discussion.....	122
Conclusion_General discussion and outlooks.....	127
1. Summary of the main results	128
2. Is it desirable to maintain a glass eel economy in France?.....	129
3. Are we seeing the emergence of more global environmental concerns about biodiversity conservation?	131
4. Conclusion	133
References	134
Supplementary material	177

List of figures

Introduction

Figure 1.1: The life cycle of eel species	23
Figure 1.2: Distribution of Northern hemisphere temperate eel species	24
Figure 1.3: Imports of live eel fry for farming into East Asia and supply of <i>Anguilla japonica</i> for farming in East Asia, 2004-2019	27
Figure 1.4: The glass eel restocking target in Eel Management Plans and percentage of target reached.....	29
Figure 1.5: Glass eel catches and destinations.....	30
Figure 1.6: Schematic representation of the thesis structure	34
Figure 1.7: Supporting discussions and partnerships between researchers and the world of environmental and species management is essential	36

First chapter

Figure 2.1: Illustration of the interactions between translocation and ecological processes in the eel's lifecycle	44
Figure 2.2: Coupled quantitative and qualitative methodology.....	46
Figure 2.3: Main journals by decade	47
Figure 2.4: Concept cloud	49
Figure 2.5: Main concepts associated with the concept of “restocking”	50
Figure 2.6: Summary of the main research issues associated with each ecological process that have been debated in the literature	51

Third chapter

Figure 4.1: Map of the different BU in France	106
Figure 4.2: Conceptual framework of the SES surrounding the restocking in the LCVS BU, with the resource units, the governance system and the various actors.....	109
Figure 4.3: Main model (model 1).....	113
Figure 4.4: Results from loop analysis examining the effects of fishing management actions	118
Figure 4.5: Results from loop analysis examining the effects of market-based management actions	120

List of tables

Introduction

Table 1.1: Data on international trade in European eels from 2009 to 2012.....	26
Table 1.2: Summary of the results of a French study on 121 PhD students.....	36

First chapter

Table 2.1: Main consensus and research gaps	55
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Second chapter

Table 3.1: The attributes and levels in the choice experiment	71
Table 3.2: Example of a choice set	73
Table 3.3: Survey objectives and data	76
Table 3.4: Descriptive statistics and characteristics of the valid sample.....	78
Table 3.5: Proportions of choices made for each scenario for the group that received additional information about the eel trade and the one that did not	84
Table 3.6: Pearson chi-square testing the null hypothesis that the distribution of choices across alternatives in each choice set is the same for both the control and the treated group	84
Table 3.7: Conditional logistic regression with the effects of interaction with the “VIDEO” variable	86
Table 3.8: Conditional logistic regression	87
Table 3.9: AIC and BIC with 2, 3 and 4 latent classes	88
Table 3.10: Latent class model estimates with three latent classes	89-90

Third chapter

Table 4.1: Table of predictions	115
Table 4.2: Sensitivity analysis	121

List of supplementary material

S1	First chapter	177
S1.1	Keywords	177
S1.2	Large corpus	177
S1.3	Leximancer parameter setting	177
S1.4	Small corpus references	186
S1.5	Main concepts (with a relevance $\geq 5\%$) revealed by the ACA	189
S1.6	Concept cloud (Gaussian distribution to facilitate the reading)	190
S1.7	Concepts associated with the “European”(a), “japonica”(b) and “rostrata”(c) concepts	191
S2	Second chapter	197
S2.1	Script of the video (French and Japanese versions)	197
S2.2	Questionnaire (English version)	199
S2.3	Probabilities a posterieuri (% by characteristic for each class)	216
S2.4	Summary of the answers to the NEP and factorial analysis	217
S2.5	Scores and proportions of high (5, 6, 7) and low (1, 2, 3) scores a posterieuri for NEP’s items.	220
S3	Third chapter	223
S3.1	Survey and data	223
S3.2	Alternative model	234
S3.3	Simulation input and outputs for model 1	235
S3.4	Simulation input and outputs for model 2	237
S3.5	Simulation input and outputs for model 3	239
S3.6	Simulation input and outputs for alternative model	239
S3.7	Simulation outputs for glass eel collapse	243
S3.8	Simulation outputs for sea-bass collapse	244
S3.9	Simulation outputs for scenario 1	245
S3.10	Simulation outputs for scenario 2	245
S3.11	Simulation outputs for scenario 3	246
S3.12	Simulation outputs for scenario 4	246
S3.13	Simulation outputs for scenario 5	247
S4	Conclusion	248
S4.1	Objectives of the survey and sample	248
S4.2	Map of the management Basin Units in France	249
S4.3	Questionnaire (in French)	250
S4.4	Script of the video (in French)	267
S4.5	The attributes and levels in the choice experiment	268

List of abbreviations

AAPPBLB	Association Agréée des Pêcheurs Professionnels en eau douce du Bassin Loire-Bretagne
AAPPED 44	Association Agréée des Pêcheurs Professionnels en eau douce de Loire-Atlantique
ACA	Automated Content Analysis
AIC	Akaike Information Criterion
ASC	Alternative Specific Constant
BIC	Bayesian Information Criterion
BU	Basin Unit
CDPMEM17	Comité Départemental des Pêches Maritimes et des Elevages Marins de Charente Maritime
CITES	Convention on International Trade in Endangered Species of Wild Fauna and Flora
COREPEM	Comité Régional des Pêches maritimes et des Élevages Marins des pays de la Loire
DCE	Discrete Choice Experiment
EMP	Eel Management Plan
ES	Ecological System
EU	European Union
ICES	International Council for the Exploration of the Sea
IGPB	International Geosphere-Biosphere Program
IIA	Irrelevant Alternatives
IID	Identically Distributed
IPBES	Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services
IPCC	Intergovernmental Panel on Climate Change
IUCN	International Union for Conservation of Nature
LCL	Latent Class Logit
LCVS	Loire Côtier Vendéen et Sèvre Niortaise
MS	Member States
NEP	New Ecological Paradigm
POs	Producer Organizations
SES	Socio-Ecological System
SS	Socio-economical System

INTRODUCTION

« Aucun scientifique publiant dans les meilleures revues internationales ne doute que, pour la très grande majorité des espèces vivantes, vivre va devenir de plus en plus compliqué. »

Nathanaël Wallenhorst, La vérité sur l'Anthropocène, 2020

Foreword

Biodiversity conservation in a context of global change

The global collapse of biodiversity

It is largely admitted that we entered the Anthropocene, concept introduced in the Earth sciences (Crutzen, 2002) and adopted by other scientific communities such as humanities and social sciences (Brondizio et al., 2016). This era is characterized by a series of global changes that have led to the current crises of biodiversity loss, habitat destruction and climate change. It also reflects the globalization of lifestyles and the emergence of large-scale environmental concerns.

The birth of the Anthropocene concept has introduced the notion of "planetary limits", defining limits beyond which human activities can lead to irreversible consequences for the planet (Castree, 2016). Among the nine boundaries defined, six has been considered transgressed including the biosphere integrity (Richardson et al., 2023), with levels of genetic and functional diversity exceeding the critical threshold. The five other transgressed boundaries concerns climate change, land system change, freshwater change, biogeochemical flows and novel entities such as synthetic chemicals and substances. Although ocean acidification is approaching its planetary boundary, the atmospheric aerosol loading and stratospheric ozone depletion are still in a safe operating space, which suggests that there is very little wiggle room to avoid chaos.

The issue of biodiversity degradation will be of particular interest to us in this thesis. Concerning this issue, it seems we are short in time to prevent a major collapse of world species as the scientific consensus has established that biodiversity is being rapidly depleted and that the planet is experiencing the sixth mass extinction (Ceballos et al., 2015; Cowie et al., 2022). The IPBES (Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services) global assessment report on biodiversity and ecosystem services (2019) indicates that of an estimated 8 million animal and plant species (75% of which are insects) around 1 million are threatened with extinction. The proportion of species currently threatened with extinction according to the International Union for the Conservation of Nature's Red List criteria averages around 25% across the many terrestrial, freshwater and marine vertebrate, invertebrate and plant groups that have been studied in sufficient detail to support a robust overall estimate (IPBES, 2019). Human actions have already driven at least 40% of reductions for terrestrial species,

84% for freshwater species and 35% for marine species, according to The Living Planet Index, which synthesizes trends in vertebrate populations (IPBES, 2019). Severe impacts to ocean ecosystems are illustrated by 33% of fish stocks being classified as overexploited and greater than 55% of ocean area being subject to industrial fishing, but inland waters and freshwater ecosystems show among the highest rates of decline.

The great deal of biodiversity conservation

Faced with the reality described in the previous paragraph, biodiversity conservation has become an urgent necessity to preserve these threatened species in order to maintain the functions they provide, including direct and indirect services to mankind.

The aim of conservation is ecosystem self-maintenance and resilience as well as the population viability of species, concepts that are synthesized as “ecological integrity” (Hansen et al., 2021; Karr et al., 2022). In modern conservation, the preservation of ecosystem functions is based on the assessment of interspecific and intraspecific biodiversity and their interactions (Cabello et al., 2012). In addition to protect species and ecosystem processes, conservation aims at protecting the resulting ecosystem services humans depend on. These services are divided into four categories in The Millennium Ecosystem Assessment (2005): provisioning, regulating, cultural and supporting. Global biodiversity loss and the associated erosion of ecosystem processes are likely to lead to a collapse in the provision of several essential services (Harvey et al., 2017).

Efforts have been made to find common ground between perspectives that focus on the preservation of nature and those that include human rights and needs, as it is increasingly recognized that biodiversity loss affects human well-being and that human behavior is key to addressing the biodiversity crisis (Cooke et al., 2022a). Despite increasing conservation efforts, the ongoing rates of biodiversity decline might highlight the shortcomings in addressing the right conservation priorities (Tittensor et al., 2014) even if temporal lags in species’ responses to conservation action could be masking our ability to observe progress towards conservation success (Watts et al., 2020).

This statement raises the issue of monitoring conservation actions in order to assess their efficiency and to be able to conclude whether or not they have been successful. It is important to take this step into account from the outset of conservation planning processes in order to

support learning and the improvement of results. However, the scientific literature highlights an imbalance between the implementation of conservation actions and their monitoring and evaluation, particularly in terms of budget allocation (Salzer and Salafsky, 2006; Buxton et al., 2020). Without monitoring and evaluating the efficiency of conservation actions, the large budgets committed to these actions are difficult to justify and learning from past experience is limited (Bottrill and Pressey, 2012). There is no uniform evaluation framework for the simple reason that the efficiency of a conservation measure can be defined in different ways. However, it is important to take into account not only ecological but also socio-economic aspects in the evaluation process (Bottrill and Pressey, 2012; Bennett et al., 2019).

The evaluation of conservation actions is therefore a complex issue that does not seem to be able to be fully studied under the prism of a single discipline (Knight et al., 2019).

The need for interdisciplinarity to address the environmental issue of biodiversity conservation

Because of its urgency and the singular nature of its subject matter, the environmental issue has popularized the use of interdisciplinarity (Pecqueux et al., 2022), particularly among researchers in the natural sciences and the humanities and social sciences who are dealing with the issue of the biodiversity crisis that will interest us in this thesis.

We have seen the emergence of a number of transdisciplinary groups bringing together a large number of researchers from all backgrounds to issue warnings on climate and environmental issues through scientific articles and reports (Magny, 2021). These increasingly insistent warnings are an extension of major international research programs, such as the IGBP (International Geosphere-Biosphere Program) or the Millennium Ecosystem Assessment, or the creation of bodies such as the IPCC (Intergovernmental Panel on Climate Change) for climate in 1988 or the IPBES for biodiversity in 2012.

With the realization that conservation efforts must encompass human dimensions, research cannot only focus on ecological considerations (Sandbrook et al., 2013; Brondizio et al., 2016; Hicks et al., 2016; Bennett et al., 2017a; Bennett et al., 2017b). Many of the biodiversity management measures implemented to conserve or restore biodiversity afterwards did not pay off. It is partly due to the fact that the underlying motivations of the various stakeholders are

not systematically taken into account (Legay, 2006). It is not enough to take the whole ecological context seriously: we also need to look at the cultural, economic and social context.

Conservation as a practice, demands a comprehensive grasp of both natural and societal systems and not only mandates cooperation between scientists from both domains, but also necessitates collaborative efforts among researchers, practitioners, policymakers, and stakeholders (Leguay, 2006; Bennett et al., 2017b).

Discussions across disciplines and between science and action are difficult but useful endeavors, at least laying the foundations for better mutual understanding and, at best, contributing to better conservation outcomes (Sievanen et al., 2012; Young et al., 2013). This integration of disciplines and stakeholders should take place at all stages of the conservation research-action cycle, taking into account the need to balance feasibility, efficiency and effectiveness (Bennett et al., 2017a) and complementary, qualitative, and reflexive assessments in addition to quantitative indicators remain critical for development, implementation, and interpretation of robust measurement systems (Hicks et al., 2016).

General introduction

1. The case study of Northern temperate Anguillid eel species conservation

1.1. Migratory fish as emblematic examples of the biodiversity collapse

As mentioned in the foreword, freshwater biodiversity is now in peril (Dudgeon, 2019) and freshwater species are at greater risk than their terrestrial counterparts (Collen et al. 2009). Almost one in three of all freshwater species are threatened with extinction (Collen et al. 2014). Among vertebrates, freshwater fish experienced a high rate of extinction in the 20th century (Guy et al., 2021). At local level, extinction or decline in the abundance of freshwater fish is the result of the cumulative effect of over-exploitation and of multiple human pressures on their aquatic environment (Mota et al., 2014; Dudgeon, 2019; Deinet et al., 2020). Migratory species of freshwater fish, which need to migrate between environments (rivers and sea) or within river systems to complete their life cycles, are disproportionately threatened compared to other fish groups (Waldmann and Quinn, 2022).

Anguilla genus is emblematic of migrating fish species and is at risk, mainly because it is subject to multiple anthropic pressures including environmental changes as well as exploitation (Jacoby et al., 2015; Jellyman, 2022). Some populations, such as the Northern temperate eel species (*Anguilla* spp.) that is the focus of this thesis, are classified by the IUCN as endangered (the American eel *Anguilla rostrata* and the Japanese eel *Anguilla japonica*) or critically endangered (the European eel *Anguilla anguilla*). The largest declines were observed between 1980 and 2010, starting with the European eel. The recruitment fell down to 10-5% of the past decades level (Jacoby and Gollock, 2014) and remains at low levels until nowadays (ICES, 2022). Moreover, temperate eel species inhabiting the Southern Hemisphere are considered threatened or near threatened. Although there is a lack of data on some of the tropical species, seven tropical species fall within Threatened Species categories (Vulnerable, Endangered, Critically Endangered) or the Near Threatened Species category, which places the tropical species at risk of following the same path as temperate species. Altogether, 10 of the 19 Anguillid eel species are evaluated as threatened or near threatened, while two are considered as Data Deficient.

The decline in the abundance of Anguillid eels is believed to result from the cumulative effect of multiple human pressures on their aquatic environment, including habitat loss (Chen et al., 2014) and dams that reduce the accessibility of growth habitats (Verreault et al., 2004; Besson et al., 2016), pathogens and pollution (Feunteun, 2002; Sjöberg et al., 2009), and overfishing (Feunteun, 2002; Tsukamoto et al., 2009; Jacoby et al., 2015).

1.2. The complexity of Northern temperate eels' species life cycle makes them particularly vulnerable to anthropogenic threats

The *Anguilla* genus encompasses 19 species/subspecies with unique life history traits, spread across tropical and temperate areas (Jellyman, 2022). This thesis focuses on the three temperate species found in the Northern hemisphere, namely European, American and Japanese eel species. The three species display very similar life history (Daverat et al., 2006; Edeline, 2007).

The mysterious existence of these species has given birth to many questions and hypotheses that are, at the very least, quite eccentric. For example, in his History of Animals, Aristotle hypothesized that the eel originated by spontaneous generation from non-living matter, specifically mud (Cresci, 2020). It was not until the end of the 19th century that eels were linked to their first life stages, the leptocephali larvae (Fig 1.1). The mysteries surrounding the eel have been unraveled little by little, but some still persist, particularly with regard to its marine phase, which is much less well known than its continental phase. Only one direct observation of a mature Japanese eel on the spawning ground occurred (Tsukamoto et al., 2013).

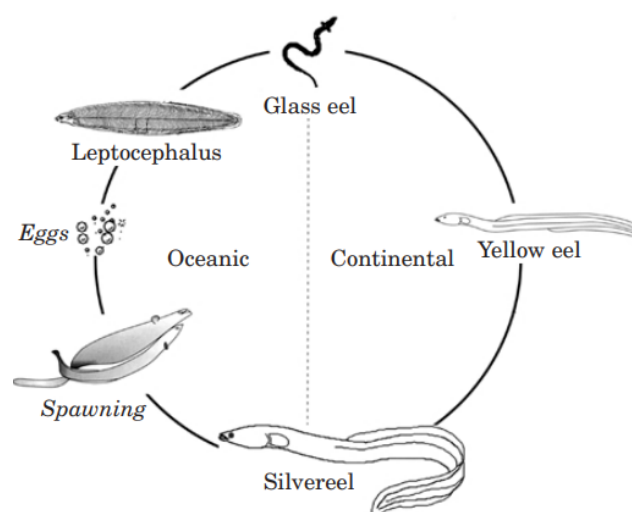


Figure 1.1: The life cycle of eel species. The names of the major life stages are indicated (Dekker, 2000)

However, it is nowadays known that the Northern temperate eels are facultative catadromous species (Tsukamoto and Arai, 2001). This migratory fish are supposed to reproduce once in their lives (semelparity) in the open ocean, and grow in continental waters. Spawning for European and American eel species is taking place in the Sargasso Sea (Miller et al., 2015) while it is happening in the West Mariana Ridge (Tsukamoto et al., 2011). Leptocephali larvae undertake a long trans-oceanic drift (Atlantic or Pacific) over hundreds or even thousands of kilometers in the case of the Japanese and European eel species, which can last from several months to years (Bonhommeau et al., 2010; Miller et al., 2015; Kasai et al., 2021). After reaching their respective continental slopes, larvae metamorphose into the post-larval transparent glass eels, which migrate from the continental shelf to the coastal areas and some will eventually start an upstream migration into fresh water, colonizing various continental habitats such as estuaries, lagoons, marshes, rivers and streams, while the other will spend their entire lifetime in brackish or saltwater (Tsukamoto and Arai, 2001; Marohn et al., 2013). The distribution areas of these three species are quite large (Fig 1.2)

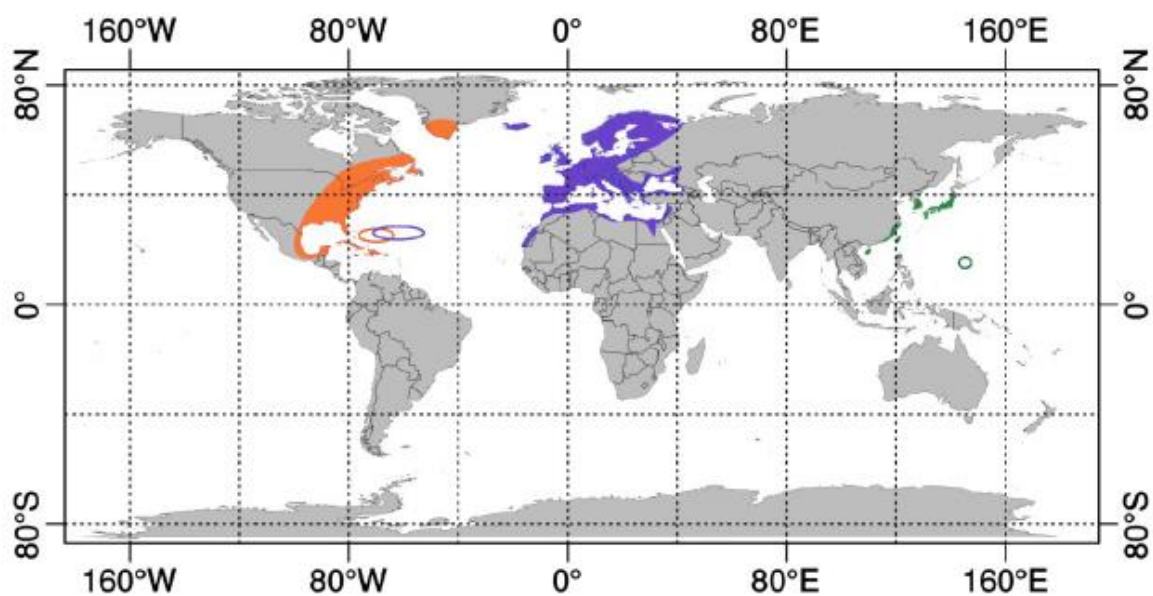


Figure1.2: Distribution of Northern hemisphere temperate eel species. American eel distribution is represented in orange, European eel distribution in purple and Japanese eel distribution in green. The supposed spawning grounds are indicated by circles (Mateo Santos, 2017)

Glass eels grow into the adult stage of yellow eel before metamorphosing in silver eel and undertake the journey across the ocean to their spawning areas (Tesch, 2003; Takeuchi et al., 2021; Wright et al., 2022). Silvering is coupled with a shift in energy allocation, from growth

to reproduction. Silver eels gather the needed stock of lipids before they migrate back because they stop eating during this long trip and still have to sexually mature (Belpaire et al., 2009).

Ecologically, adult eels are generalist predators and sometimes scavengers (Sporta Caputi et al., 2020), and serve as indicator, umbrella and flagship species for the conservation of freshwater biodiversity (Itakura et al., 2020). *Anguilla* spp. are both a biological resource of considerable ecological and socioeconomic importance (Tamario et al., 2019) and a guarantee of good aquatic environmental quality (Plum and Schulte-Wülwer-Leidig, 2014; Itakura et al., 2020).

1.3. The fragility of Northern temperate eel species is exacerbated by their high economical value

The three continental stages *i.e. glass eel, yellow eel, silver eel* of the Northern temperate eel species are harvested and traded in their distribution areas, with significant consumption largely concentrated in Eastern Asian countries, including Japan, China, and South Korea. This surge in eel trade is predominantly driven by Japan, where eel holds a special place in culture and cuisine. Japan's cultural heritage includes festivities such as the "*Doyo no Ushi*" (Eel Festival) and the popular dish "*Kabayaki*" (Kaifu et al., 2019), a traditional culinary delight from the Edo period, reflecting the country's profound connection to eel. In the broader context, seafood accounts for over 40% of annual animal protein consumption, emphasizing its pivotal role (Ganapathiraju et al., 2019).

However, as the Japanese eel population has declined and local catches have diminished, these East Asian countries have become increasingly reliant on importing eel from other species, primarily the European eel. In the early 21st century, Norway and France were the primary European exporters, along with Northern African countries such as Tunisia, Turkey, Morocco, and Algeria (Table 1.1).

*Table 1.1: Data on international trade in European eels from 2009 to 2012 (MNHN, 2014).**Source: CITES Trade Data Base WCMC (extracted on 22/07/2014)*

Area	Country	Export (kg) CITES before the zero-ban export (2009-2010)	Export (kg) CITES after the zero-ban export (2011-2012)
EU	28 State Members	27487	0 (excepted Greece 1650 kg)
Non-EU	Norway	214052	0
	Tunisia	45961	20580
	Turkey	14866	4790
	Morocco	36752	65567
	Algeria	22000	0

Historically, Japan was the epicenter for eel production and consumption, but today, China has taken the lead in both aspects. China's reliance on imported eel juveniles to support aquaculture farms, where these young eels are grown, stems from the inability to reproduce eels on a mass scale (Masuda et al., 2012). Even though no eel fishery and farming are to be found there, Hong Kong also plays a significant role in the eel trade, serving as an intermediary for eels imported and subsequently re-exported to China, Japan, or South Korea (Shiraishi, 2020).

Nevertheless, stringent measures have been imposed on the trade of European eel due to the species' recruitment and catches drops (WGEEL, 2019). European eel was initially listed in Appendix II of the Convention on International Trade in Endangered Species of Wild Fauna and Flora (CITES) in 2007, followed by a ban on extraterritorial trade in 2010. The prohibition of exporting European eels (by-products included) outside the European Union (EU) might allow to safeguard the resource and to maintain an economic framework for glass eels in Europe (MNHN, 2014). As a result of this ban, several direct consequences have been observed. Prices for eels have significantly decreased within the EU, dropping from previous levels of up to €700 or even €1000 per kilogram on the Asian market (Nielsen and Prouzet, 2008) to €200-€500 per kilogram in France, the largest European producer. Conversely, the capture and prices of American eel have surged, despite its endangered status (MNHN, 2014) and imports of American eel have increased in Asian countries (Fig 1.3). Additionally, imports of European eel continue from non-EU countries not subject to the ban. The export ban has notably allowed Morocco to become the leading exporter, with exports increasing by 28,815 kg in 2 years (Table 1.1).

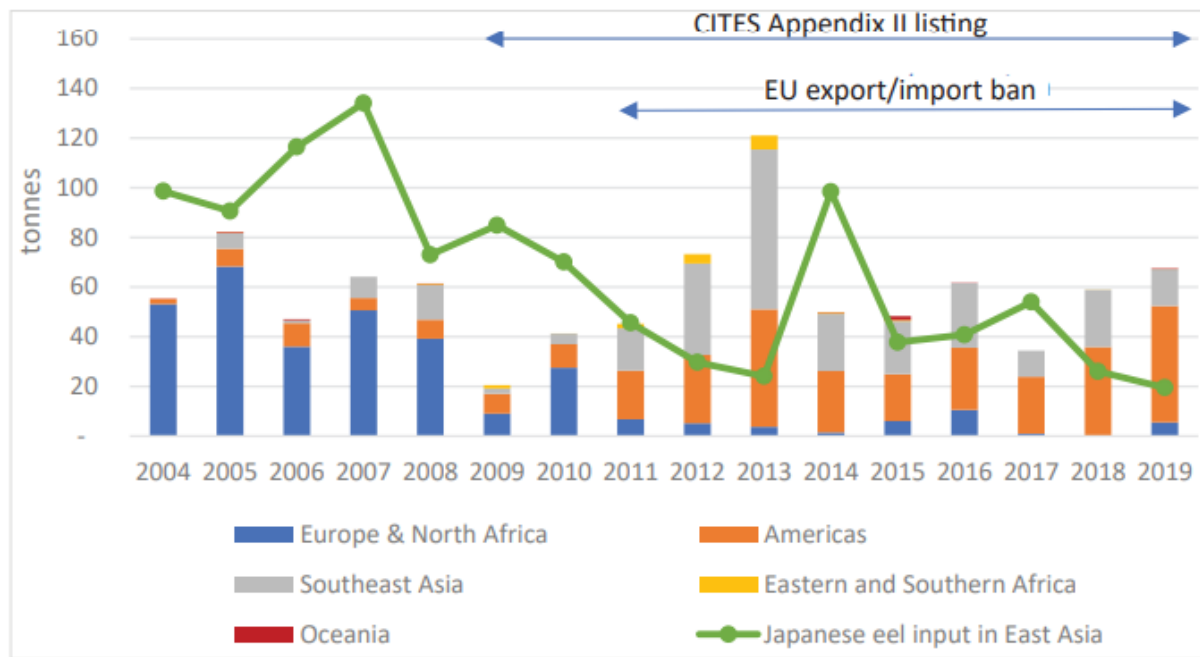


Figure 1.3: Imports (t) of live eel fry for farming (all sizes) into East Asia (excluding trade between East Asian countries/territories) and the supply of *Anguilla japonica* for farming in East Asia, 2004-2019. Europe and North Africa (likely to be *A. anguilla*); Americas (likely to be *A. rostrata*); Southeast Asia (likely to be *A. bicolor* and other tropical *Anguilla* species); east/Southern Africa (likely to be *A. mossambica* and other tropical species); Oceania (likely to be *A. australis*). Note: supply of European eel for farming in East Asia was reported by fishing season, data for the 2018-2019 fishing season is for example recorded in the figure for 2019; supply of *A. anguilla* for farming in East Asia in the 2013-2014 fishing season seems to have been overreported because of it being the base year to set input quota (Kaifu et al., 2019). (Shiraishi, 2020)

Furthermore, despite the ban, imports of glass eels were recorded in East Asian Customs data every year until 2016 (Shiraishi, 2020). It is suspected that some aquaculture producers may be sourcing their glass eels from illegal channels (World Wildlife Crime Report, 2020). The grey and scientific literature suggests that North African countries may facilitate the illegal export of European eels to East Asia (Shiraishi, 2020; Alonso and van Uhm, 2023). Even though illegal fishing and trade of European eel existed before the export ban (Shiraishi, 2020), the black market has become more organized since the ban, involving various stakeholders of the fisheries eel sector, including professional fishermen, poachers, collectors, and intermediaries (Alonso and van Uhm, 2023). It's worth noting that illegal harvesting and trade are encouraged by the risks of intentional or unintentional misidentification of different eel species, particularly between European eel and America eel, and the relative ease of capturing and transporting the

species (MNH, 2014). Although official statistics do not permit the tracing of illegal flows, recent studies utilizing molecular techniques confirm the presence of European eel in gastronomic and food markets worldwide (Nijman and Stein 2022).

Finally, the eel trade involves species broadly distributed across the globe, with demand primarily driven by East Asian countries. Despite growing threats to the species, demand remains high, emphasizing the critical need for conservation efforts.

1.4. Restocking of Northern temperate eel species: between conservation and exploitation

Despite their status of threatened species, eel species have been managed as natural resources before being preserved as endangered species within the framework of conservation. Because of their status of exploited fish with a high economic value, eel stocks have been managed with a view to increase biomass availability for fisheries. For the three Northern hemisphere temperate species, glass eel fisheries were still allowed within conservation management plans whereas partial or total fishing bans were implemented (Fishery Management Report No. 36 of the Atlantic States Marine Fisheries Commission; Interstate Fishery Management Plan for American Eel, 2000; *Décret n° du 22, 2010–, 1110 relatif à la gestion et à la pêche de l’anguille*; The Bureau of Fisheries of People’s Republic of China et al., 2014). The coexistence of exploitation and conservation in this specific case has led to the implementation of actions that ambiguously mix objectives. This ambivalence is best exemplified by actions to translocate young eels from a site of capture to a site of release, termed “restocking” or “stocking” (MacGregor et al., 2008; Dekker and Beaulaton, 2016; Wakiya et al., 2022). Eel translocation is carried out with wild juveniles, as the artificial reproduction of eels does not allow for mass production (Masuda et al., 2012). In the last decade, the continued decline of the three Northern Hemisphere temperate eel species has reinforced the attractiveness of translocation projects as a conservation approach to prevent the collapse of eel stocks. In the case of European eel, translocation actions are undertaken by commercial fishery actors. In Japan, where the Fisheries Act has mandated that inland water fishery cooperatives which catch eels in rivers and lakes increase their eel populations, these cooperatives typically restock eels to fulfil this obligation (Kaifu, 2019).

In the European Union, restocking has been mentioned in the European Council Regulation (No. 1100/2007 published in September 2007) as one of the management measures to implement in order to meet an escapement target (40% of the silver eel pristine biomass) and to enhance fisheries. The Regulation required all Member States (MS) host for the European eel to establish management plans aiming the conservation of the species. The benefit of restocking has been advocated since 1840 but it is highly controversial. EU regulation sets a target of 60% of catches to be used for restocking by Member States that have chosen to introduce this measure in their management plan. Like other MS, France has implemented restocking measures since 2011. It is the country with the highest eel landing records for both stages: juveniles (glass eels) and adults (WGEEL, 2019). Adult stages are sold on the food market while glass eels are used for restocking and consumption purposes. French glass eels are used to restock French rivers but are also sold to other MS that have chosen to set up restocking schemes, mainly Germany, the Netherlands and Denmark (FranceAgriMer, 2023). This measure probably contributed to the fact that there was no shift in landings following the 2009 ban (WGEEL, 2019). Compared to restocking, glass eel fishing for consumption is a highly lucrative niche for professional fisheries. In 2018, French fishermen were selling a kilogram of glass eel for approximately €250 for restocking and €380 for consumption (Feunteun and Prouzet, 2020). This price difference presents real challenges for the conservation of European eels. It can be assumed that this is one of the reasons why the restocking targets set by Europe are not being met (Fig 1.4).

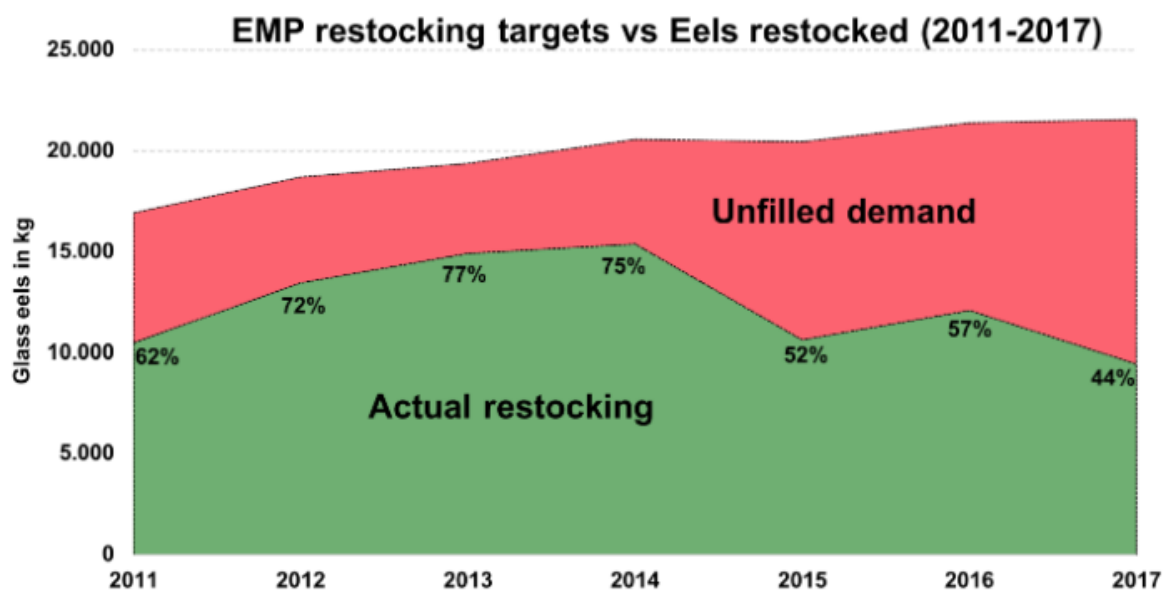


Figure 1.4: The glass eel restocking targets in Eel Managements Plans (EMP) and percentage of target reached (Stein, 2018a)

Moreover, illegal trade seems to increase the complexity of conservation challenges, knowing that a kilogram of glass eel can be sold for between €800 and €3,000, and the net margin for “operators” is over €1,000 on the black market (FranceAgriMer, 2014). Under these conditions, even honest fishers are unable to resist the attraction of illegal harvests for export to Asia (Kaifu et al., 2019). It is legitimate to wonder whether restocking actions might be contributing to this illegal trade. The traceability of glass eels in Europe is a real problem (Shiraishi, 2020), and this issue seems to concern glass eels destined for restocking more than glass eels destined for consumption (Fig 1.5).

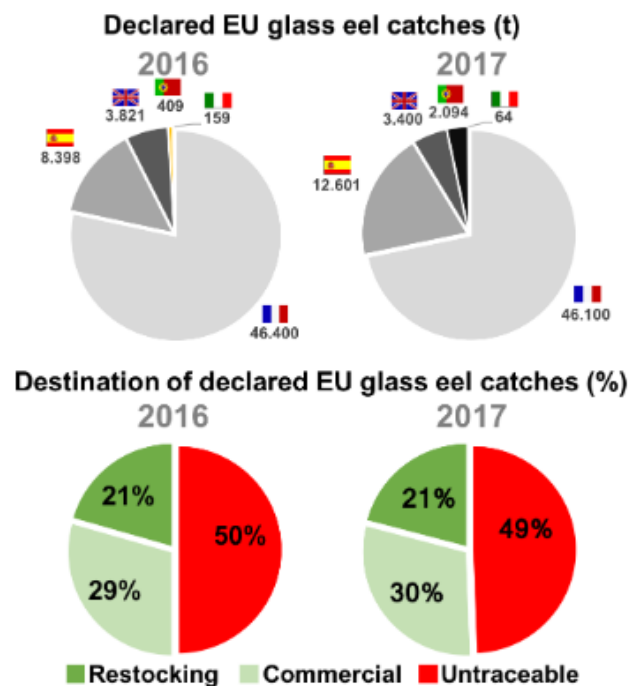


Figure 1.5: Glass eel catches and destinations (Stein, 2018b)

2. The framework of Socio-Ecological systems and use of mixt methods to understand and evaluate the efficiency of eel restocking

2.1. Objective of the thesis

As mentioned in the foreword, one of the major challenges in conservation is to evaluate the measures put in place in order to preserve threatened species. This issue has been interested me in this thesis, in which I offer an evaluation of eel restocking as a conservation action. Previous review papers have tried to discuss the efficiency of eels’ translocation techniques on the basis

of selective studies (Dekker and Beaulaton, 2016) or by collecting and combining expert knowledge and opinions (ICES, 2016). But to date, there is no complete overview of the benefits and risks associated with eel translocation and their implications for conservation, based on a global and systematic review of evidence from the academic literature. In addition, the complex socio-economic context described in the first part of this introduction leads us to believe that these aspects should be taken into consideration when assessing eel restocking as a conservation measure.

The research questions raised by this thesis project, with complex and global objectives, cannot be addressed by a single discipline. For this reason, the general objective of the research is to develop an integrative approach, involving the cross-disciplinary contribution of ecology and economics, to the evaluation of restocking as an action to restore the eel's populations, for both conservation and economic purposes.

The main objective of this thesis is therefore to assess the efficiency of restocking as a conservation tool for eel species by **adopting a social-ecological system perspective within an interdisciplinary approach**. This social-ecological system thinking recognises restocking as complex coupled human-nature interactions encompassing ecological processes, socio-economic processes and their interactions. A thorough understanding of the (in)efficiency of the social-ecological interactions in restocking following three complementary research axes has been elaborated. A variety of methodologies has been used, both qualitative and quantitative. It allows me to highlight that an interdisciplinary evaluation is not intended to quantify everything. Quantitative modelling is obviously a tool of choice for interdisciplinary work, it is important to leave a significant place for descriptive and more qualitative analyses.

2.2. First research axis

In the first chapter, I extracted from scientific literature **which biological and ecological interactions influence the efficiency of restocking as eels' translocation**. Eels' translocation can follow different approaches, depending on the objectives and context. Assessing the outcome of translocation projects aiming at restoring eel population is complex, mainly because the last part of its lifecycle, reproduction, is unresolved and has never been observed in the wild. A systematic review was combined with a narrative review and I first generated a data set of 956 articles published between 1933 and 2021 and apply automated content analysis to identify key controversies about the effect of translocation on eel biological processes. The

main thematic associated to translocation were survival, migration and selection by environment. These thematic were further analyses within a narrative review on the basis of a selection of recent articles. The review revealed that there is a consensus on the fact that translocation interacts with natural selection processes (phenotype/environment mismatch), and that translocated eels migrate towards the reproduction area as silver eels, but there are still research gaps on the comparative survival of translocated and wild eels. An emerging thematic was the effect of eel translocation at the community level. Based on review findings, the future research has to focus on the direct comparison of the ecology of translocated eels and their wild counterparts in the natural environment as well as the study of the translocation actions' impact at community level.

2.3. Second research axis

Achieving the dual objectives of biodiversity conservation and sustainable use of fish resources requires to reduce the demand from eels' consumers. However, quite little is known about consumers' preferences for the adoption of specific regulation policy. The main purpose of the second chapter is to contribute on this subject. The first quantitative study to assess **Japanese consumers' preferences for policy tools aiming eels' conservation** was then conducted. Despite stock decline of Japanese eels, eels remain an important food resource in Japan and constitute reference of Japanese cuisine. Eels consumed in Japan come from three sources: fisheries, eels farming and importation of live eels from other Asian countries. Using a discrete choice experiment, the aim of this research was to analyse the preferences and trade-offs made by individuals regarding different policy levers for eel conservation in Japan (e.g. direct regulation of consumption, promotion of substitute species, price-based policy, development of eel aquaculture, information-based policy, fight against illegal eel trade by controlling imports). The current situation served as the reference scenario. Individual environmental awareness and commitment, as well as income level, age and location (rural or urban) were considered as part of a model specification with three talent classes. A sample of 1088 individuals was used. The results showed that low-income consumers and those less sensitive to environmental issues have a strong preference for the status quo alternative. In contrast, consumers with environmental awareness and commitment had strong preference for stricter market regulation policy. They were less sensitive to information based-policy, and were supportive of price-

based policy. Finally, high-income, less committed consumers, and those who lived in rural areas show preferences for consumption behaviour changes.

2.4. Third research axis

On the basis of the results obtained in the first chapter, it can be argued that restocking alone is not a sufficient management measure to rebuild the eel population. In order to conserve and sustainably use eels, demand regulation measures are necessary and expected, as shown in chapter 2. The aim of the third chapter of the thesis was therefore to understand the effectiveness of restocking as a **socio-ecological system (SES) involving interactions between ecological, socio-economic and institutional factors**. This perspective was applied in order to explore issues concerning the management of the European glass eel fishery within the Loire Basin Management Unit in France. This management basin is of particular interest as France is the only country that has a system of fishing quotas for glass eel to prioritise restocking projects, such that in theory, only unused quotas can supply the domestic consumption market. This management territory was characterized as a socio-ecological system, using a parsimonious set of variables. The interactions between these variables were reconstructed based on the existing literature and results of a survey among professional fishers of the study case. A qualitative loop analysis that exploits the structure of these interactions was performed, in order to identify the pathways responsible for the propagation of impacts and feedbacks that modulate the effects of different management measures, in complement of eel restocking, on fishing effort, stock level, and fishers' income, then advancing an ecosystem-based management of glass eels' fishery. The effects of lower allowable quota for consumption market, fishing effort regulation or shift to complementary/accompanying species, and price-based instrument (subsidised price for the restocking sector or additional tax for the consumption sector) were tested. A major contribution of this paper is that ecologically and socio-economically viable scenarios, all of which hinge on the implementation of measures aimed at alleviating fishing pressure on elver resources.

I have summarized these aspects on the schematic representation of my thesis structure (Fig 1.6). I have also added the two last lines to show the diversity of concepts I am mobilizing, which are either specific to ecology or environmental economics, or at the border between the two disciplines. It also summarizes the disciplines and sub-disciplines that I embraced in this PhD.

PhD subject : "Think global to act local : an interdisciplinary evaluation of the restocking of temperate eel species (*Anguillid spp.*) as a conservation action"

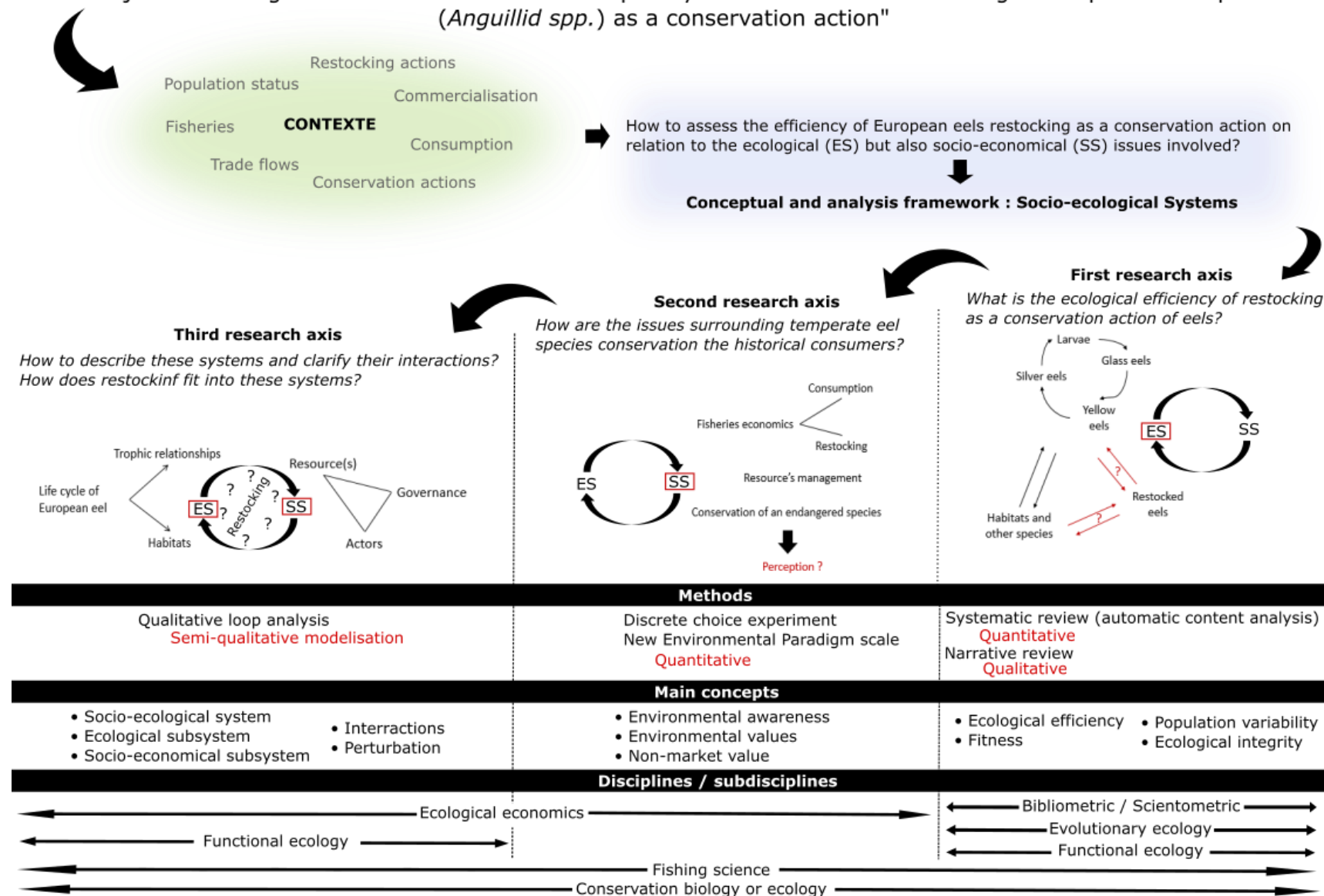


Figure 1.6: Schematic representation of the thesis structure

2.5. Interdisciplinarity in thesis: a unique experience

To finish this introduction, I would like to revisit some reflections I have had over these four years regarding the interdisciplinary nature of my thesis. I naturally questioned what interdisciplinarity really meant and why I chose this term over others such as pluridisciplinarity, multidisciplinary, or transdisciplinarity. You might have guessed, but my PhD topic has undergone numerous name changes. My co-supervisors and I have navigated between the terms of multidisciplinary, interdisciplinary, and transdisciplinary. These distinctions are not always clear-cut. So, I delved deeper into the subject to better position my work from an epistemological perspective and gain a concrete understanding of my research. It seems that the degree of integration or hybridization between disciplines is the key factor (Létourneau, 2008; Frodeman et al., 2010). While multidisciplinary might involve the use of methods or concepts from other disciplines in a multidisciplinary project, interdisciplinarity implies a more profound integration. It requires a shared base to address complex research questions, such as the development of a specific conceptual and theoretical framework or the implementation of specific methods. Some even describe a higher degree of hybridization, surpassing interdisciplinarity, termed as transdisciplinarity. Based on these definitions, it seems justified why I favor the term interdisciplinarity for my research.

Another point I would like to address is the rationale behind interdisciplinarity. In the foreword, I already mentioned the need for this approach to tackle complex questions facing researchers today. When inquiring about the reasons for practicing interdisciplinarity, researchers bridging natural sciences and social sciences (intersectoral collaboration) exhibit a different distribution of motivations according to a survey conducted in a French interdisciplinary laboratory (Prud'homme and Gingras, 2015). Among this group, a minority, primarily composed of young researchers, cite purely academic interests. More commonly, the promise of increased access to public decision-making is the driving force. Personally, my desire for an interdisciplinary thesis is motivated by the potential for both academic and sociopolitical impact. I have taken it to heart to consider and involve actors beyond researchers in the thought process, particularly managers and fishermen, and to a lesser extent, consumers (Fig. 1.7).

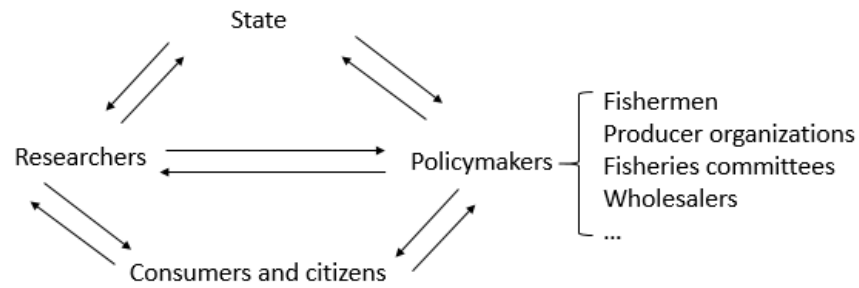


Figure 1.7: Supporting discussions and partnerships between researchers and the world of environmental and species management is essential (inspired from Legay, 2006)

Throughout my thesis, I have read the works of three French PhD students who tackled the interdisciplinary issue in their theses (Chassé et al., 2020). They conducted a survey of 121 French PhD students, revealing several positive aspects, some of which I identify with (Table 1.2). These include fostering open-mindedness, improving perspective-taking, and facilitating applied research. However, the study also highlighted three drawbacks, such as challenges with supervision, the academic framework that can impede this type of research, and instances where PhD students may have to manipulate tools outside their field of expertise, leading to confusion and a feeling of not specializing in anything.

Table 1.2: Summary of the results of a French study on 121 PhD students (80% non-monodisciplinary and 6% cross-sectorial i.e. Natural science – humanities and social sciences) (adapted from Chassé et al., 2020)

<ul style="list-style-type: none"> ▪ Open-mindedness and hindsight ▪ Results and data more robusts ▪ Encourage global and systemic vision ▪ Better apprehension of studies complexity ▪ Stimulate interactions between disciplines ▪ Open up professional possibilities ▪ More possibilities for applied research 	<ul style="list-style-type: none"> ▪ Supervisory difficulties ▪ PhD structure and academic framework example: doctoral schools in France ▪ Use of poorly understood methods

This introspection led me to the following question: can a researcher call himself interdisciplinary? The aim isn't to resurrect the scholars of the past, but I do agree with those

advocating for the training of interdisciplinary researchers. I believe, as Agnès Pivot, who has spoken extensively about interdisciplinarity, that what she terms "affecto societatis" (Pivot and Mathieu, 2007) or the willingness to collaborate on an equal footing in collective work is essential for the success of interdisciplinary scientific projects. The presence of interdisciplinary researchers could help bridge the gap between disciplines and play the role of boundary crossers (Chassé et al., 2020), as Roxane Sansilvestri suggested during a dedicated conference.

At last, Elise Demeulenaere (2022) reminds us that each interdisciplinary experience is unique, bringing both enthusiasm and challenges, but also that but also that subjective feedback has a productive and heuristic virtue. In my case, I was fortunate to conduct my thesis between two research units with different disciplinary orientations but located in the same place. Despite a tense political environment, some researchers accustomed to working with one another in both units allowed me to evolve in terms of the interdisciplinary aspect of my thesis. Conversely, I also observed how simply mentioning the title of my thesis could trigger reluctance. Not everyone is in favor of interdisciplinarity, especially when practiced by young researchers. Moreover, informal discussions among researchers are essential for interdisciplinary projects (Levain, 2022), and the shift to remote communication due to a certain global pandemic, in my opinion, has only added difficulty to the initial challenge.

It is worth noting that my reflections predominantly draw from French literature. This may not be representative of your observations or experiences, but since I chose to share my personal experience, it made more sense to replace it in a French context.

FIRST CHAPTER

Eel translocation from a conservation perspective: a coupled systematic and narrative review

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Eel translocation from a conservation perspective: A coupled systematic and narrative review

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« There has been an eel question ever since the existence of natural science. »

Leopold Jacoby, *The eel question*, 1880

Eel translocation from a conservation perspective: a coupled systematic and narrative review

Abstract

Translocation is used as a conservation action on a large panel of species, but efficiency of such a measure is still under investigation. This study reviews and synthesizes the existing research evidence to address how translocation of eels could be efficient from a conservation perspective. *Anguilla spp.* are endangered and translocation has been used to manage their population since the middle of XIXth century. Eels' translocation can follow different approaches, depending on the objectives and context. Assessing the outcome of translocation projects aiming at restoring eel population is complex, mainly because the last part of its lifecycle, reproduction, is unresolved and has never been observed in the wild. We thus combine a systematic and narrative review approach. We first generated a data set of 956 articles published between 1933 and 2021. Based on a thematic analysis, we linked eel life traits with the main concepts identified in the corresponding corpus. This quantitative approach revealed key controversies about the effect of translocation on eel biological processes. The main thematic associated to translocation were survival, migration and selection by environment. These thematic were further analyses within a narrative review on the basis of a selection of recent articles. The review revealed that there is a consensus on the fact that translocation interacts with natural selection processes (phenotype/environment mismatch), and that translocated eels migrate towards the reproduction area as silver eels, but there are still research gaps on the comparative survival of translocated and wild eels. An emerging thematic was the effect of eel translocation at the community level. Based on review findings, the future research has to focus on the direct comparison of the ecology of translocated eels and their wild counterparts in the natural environment as well as the study of the translocation actions' impact at community level.

1. Introduction

The conservation of aquatic ecosystems is a major challenge worldwide, as freshwater ecosystems are disproportionately affected by the global changes underway (Albert et al., 2020; Cooke et al., 2022b). Freshwater biodiversity provides key ecosystem services, and management actions are striving to restore a “good level” of freshwater biodiversity (Vörösmarty et al., 2010; Szabolcs et al., 2022). The aim of conservation is ecosystem self-maintenance and resilience as well as the population viability of species, concepts that are synthesized as “ecological integrity” (Hansen et al., 2021; Kaar et al., 2022). In modern conservation, the preservation of ecosystem functions is based on the assessment of interspecific and intraspecific biodiversity and their interactions (Cabello et al., 2012). Recently, conservation efforts began targeting rare species that provide rare functions (Violle et al., 2017). Rare functions were found to contribute disproportionately to ecosystem integrity (Bracken and Low, 2012). The rarity of species and associated functions is defined not only in terms of the quantitative scarcity or abundance of living organisms, but also according to the uniqueness of the traits and phylogeny (Violle et al., 2017).

Eels of the genus *Anguilla* are phylogenetically and ecologically rare fish species worldwide (Tsukamoto et al., 1998). The *Anguilla* genus encompasses 19 species/subspecies with unique life history traits, spread across tropical and temperate areas (Jellyman, 2022). *Anguilla* species are migratory fish. They reproduce once in their lives (semelparity) in the open ocean, and grow in continental waters. Their larvae travel across the oceans or seas. They metamorphose into glass eels and colonize various continental habitats such as estuaries, lagoons, marshes, rivers and streams before growing into yellow eels. After their growth phase, yellow eel become silver eel and undertake the journey across the ocean to their spawning areas (Tesch, 2003; Takeuchi et al., 2021; Wright et al., 2022). *Anguilla spp.* exhibit great intraspecific diversity with alternative life histories, in other words facultative catadromy (Tsukamoto et al., 1998). Ecologically, eels are generalist predators and sometimes scavengers (Sporta Caputi et al., 2020), and serve as indicator, umbrella and flagship species for the conservation of freshwater biodiversity (Itakura et al., 2020). *Anguilla spp.* are both a biological resource of considerable ecological and socioeconomic importance (Tamario et al., 2019) and a guarantee of good aquatic environmental quality (Plum and Schulte-Wülwer-Leidig, 2014; Itakura et al., 2020).

Overall, the *Anguilla* genus is at risk, mainly because it is subject to multiple anthropic pressures including environmental changes as well as exploitation (Jacoby et al., 2015;

Jellyman, 2022). All temperate eel species inhabiting the Northern Hemisphere are considered threatened by the International Union for the Conservation of Nature (IUCN). The three Northern Hemisphere temperate species that have been widely exploited are either critically endangered (*A. anguilla*) or endangered (*A. rostrata*, *A. japonica*). Although there is a lack of data on some of the tropical species, seven tropical species fall within Threatened Species categories (Vulnerable, Endangered, Critically Endangered) or the Near Threatened Species category, which places the tropical species at risk of following the same path as temperate species. Moreover, both temperate eel species inhabiting the Southern and Northern Hemisphere are considered threatened or near threatened. Altogether, 10 of the 19 Anguillid eel species are evaluated as threatened or near threatened, while two are considered as Data Deficient.

The status of exploited fish with a high economic value explains why eel stocks have been managed with a view to increase biomass availability for fisheries. Eels were managed as a natural resource before being preserved as endangered species within the framework of conservation. The coexistence of exploitation and conservation in this specific case has led to the implementation of actions that ambiguously mix objectives from both spheres. This ambivalence is best exemplified by actions to translocate young eels from a site of capture to a site of release, termed “restocking” or “stocking” (MacGregor et al., 2008; Dekker and Beaulaton, 2016; Wakiya et al., 2022). Eel translocation is carried out with wild juveniles, as the artificial reproduction of eels does not allow for mass production (Masuda et al., 2012). In the last decade, the continued decline of the three Northern Hemisphere temperate eel species has reinforced the attractiveness of translocation projects as a conservation approach to prevent the collapse of eel stocks.

Translocation has been carried out with a large number of taxa, including flora and fauna (Berger-Tal et al., 2020). Yet, the necessity and potential usefulness of existing translocation projects or programs as conservation tools have been largely questioned (Pérez et al., 2012; Resende et al., 2020). From a conservation perspective, translocation is considered successful when full ecological integrity is achieved for the species of interest, including its socio-economic dimensions (IUCN guideline, 2013; Kaifu, 2019). However, identifying characteristics or criteria that distinguish successful from unsuccessful translocation actions remains a complex task for conservation managers. Lack of baseline knowledge (*i.e.* species’ biology and ecology, suitable habitat, and species migratory and dispersal behavior) is one of

the main factors perceived as a barrier to efficient translocation protocols (Berger-Tal et al., 2020).

In the case of eels, translocation can follow different approaches, depending on the objectives and context; in particular, “reintroduction” aims at introducing eels in eel-free habitats or at least in habitats where eels have not been observed recently, while “reinforcement” seeks to increase the number of eels in a habitat they already occupy (Lee and Rahman, 2018; Smith et al., 2018; Kitada, 2020; Carcamo et al., 2021). Previous review papers have tried to discuss the efficiency of eels’ translocation techniques on the basis of selective studies (Dekker and Beaulaton, 2016) or by collecting and combining expert knowledge and opinions (ICES, 2016). But to date, there is no complete overview of the benefits and risks associated with eel translocation and their implications for conservation, based on a global and systematic review of evidence from the academic literature.

This study provides the first endeavor to conduct a systematic review of the academic literature associated with eel translocation, to describe and discuss key issues related to species conservation. The objective is to provide a comprehensive and synthetic description of what is known about the evolutionary and ecological processes underlying translocation of eel. In addition to facilitate the grasp of the restocking impact as a conservation action, understanding these processes may be more important than ever in the face of intense anthropogenic impacts, such as climate change (Olden et al., 2011; Thomas, 2011) and habitat fragmentation (Germano et al., 2015).

Compared to meta-analyses, which have been used in ecology and evolutionary biology for several years, systematic reviews are rare and are now becoming an established method to aggregate research results (O’Dea et al., 2021). A systematic review can use qualitative or quantitative methods for synthesizing studies (Gough et al., 2012). This review uses a combination of (quantitative) literature synthesis techniques and (qualitative) narrative review. More specifically, we first performed a systematic review based on an automated content analysis (ACA) of all the selected articles (Nunez-Mir et al., 2016). We use the Leximancer software to address the extent and the nature of the research activity. We also use it to identify key concepts and dominant themes in order to give an overview of main research interests and findings. As such, the synthetic review of the literature developed in this article should be understood as an exploratory approach. It does not necessarily assess the quality of the studies that meet the inclusion criteria. However, in comparison with previous reviews, it demonstrates

the value of undertaking a full systematic review to take into account the evolution of the field toward conservation issues. We complete our analysis with a comprehensive narrative review based on a subset of articles that would be representative of the major themes and sub-themes that emerged from the full systematic review. The narrative review method enables us to capture and generalize the main theoretical foundations, methodological approaches and results that have been achieved from the identified themes and sub-themes.

2. Material and method

2.1. Conceptual background and review framework

Assessing the outcome of translocation projects aiming at restoring eel population is complex, mainly because the last part of its lifecycle, reproduction, is unresolved and has never been observed in the wild. Therefore, reproductive success cannot be evaluated, making it difficult to assess eel fitness, defined as the ability to survive and produce viable offspring (ICES, 2016). Translocation practices can therefore only be evaluated based on the fitness gain of eels during their continental growth and the onset of their maturation phase. This aspect has fueled a fierce debate over the pros and cons of eels' translocation. In addition, the ecology of the translocated species across their life cycle must be considered as a whole. The displacement of young eels from their habitat of collection to a recipient water area interacts with their life history path. Translocation might, for example, affect the individual eel's ability to survive (Ovidio et al., 2015; Félix et al., 2021; Newhard et al., 2021; Nzau Matondo et al., 2022) and adapt to a new environment (De Meyer et al., 2020), as well as the maturation of gonads (Marohn et al., 2013; Couillard et al., 2014) and the eel's ability to migrate to the spawning areas (Prigge et al., 2013; Westerberg et al., 2014; Sjöberg et al., 2016; Béguer-Pon et al., 2018). At the population level, translocation can interfere with intraspecific social interactions and density-dependent processes that regulate resource allocation and sex determination (Geoffroy and Bardonnnet, 2012; Côté et al., 2015; Stacey et al., 2015;). At the ecosystem level, the introduction of eels in eel-free habitats might change the community composition and functioning (Félix et al., 2020; Nzau Matondo et al., 2021).

Despite limited information about the marine phase of eel reproduction, the efficiency of translocation may be assessed using the existing knowledge on the biology and ecology of eel

in continental areas. Evolutionary and functional ecology can provide valuable frameworks to analyze and compare studies on the basis of key concepts relevant to conservation: individual eel fitness, population viability and ecological integrity afforded by eel translocation. Specifically, investigating the ways in which translocation practices interact with life history traits (growth, survival, behavior), demography (sex ratio, abundance), and ecosystems (trophic interactions, community composition) is critical to determine how effective eel translocations are at different scales. A summary of these interactions is provided in Figure 2.1.

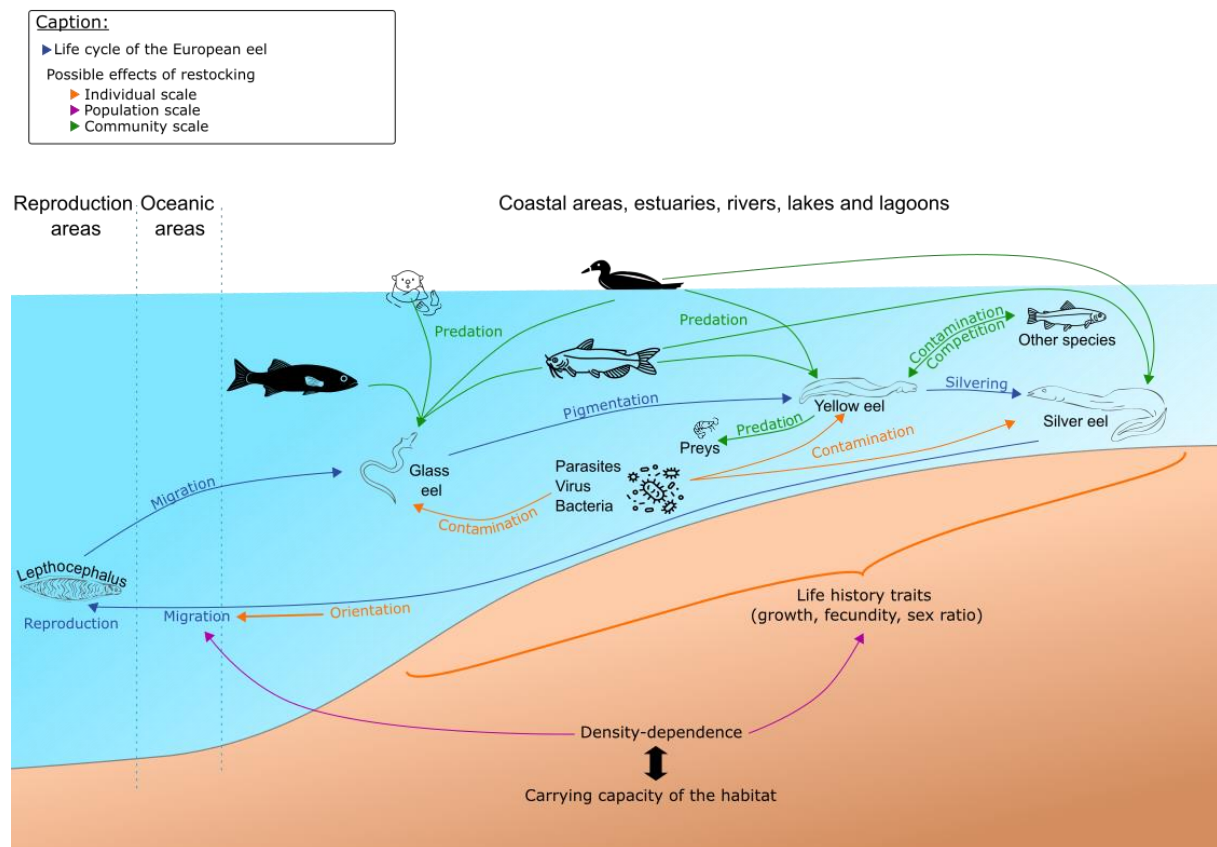


Figure 2.1: Illustration of the interactions between translocation and ecological processes in the eel's lifecycle. Warning: the proportions of the different areas and species are not realistically represented.

2.2. Literature search and selection

Literature search is a key step in systematic review. Our corpus consisted of all scientific articles we could find online, written in English and published before 2022. We included articles that dealt with either of the three Northern hemisphere temperate eel species, as these are the most studied in the scientific literature in the context of translocation, because of their commercial

importance. We used the Web of Science (WoS) citation indexing service, Google Scholar, Springer, and ScienceDirect to obtain an exhaustive list of peer-reviewed articles. We performed a search query combining (i) keywords for proxies to “eel translocation” such as “translocation” or “restocking”, (ii) keywords for the denomination of eel species at their different life stages, (iii) keywords for biological or ecological processes, (iv) proxies for the concept of effectiveness, and (v) habitats. We thus established a list of 39 keywords (supplementary material S1.1). The ScienceDirect and Google Scholar search engines could not process more than 15 keywords simultaneously for the present study. We therefore proceeded to an iterative selection of 15 of the 39 keywords. We obtained a shortlist of 15 keywords (Fig. 2.2) by comparing the top articles for each query output. The full PDF text of these articles was collected from the publishers’ websites and Google Scholar, with the help of 25 people to speed up the process (Fig. 2.2).

2.3. Synthetic review with automated content analysis

Most systematic review studies perform automated content analysis (ACA), to synthesize and analyze the titles, keywords, and abstracts of articles (Westergaard and al., 2018; McCallen et al., 2019). We analyzed the entire article text, since the word or synonyms for translocation may only have been located in the discussion section. Various tools can be used to carry out automatic content analysis (Nunez-Mir et al., 2016). Since we had a large number of articles in PDF format, we used the Leximancer software (see details in Appendix 3). We performed an ACA to identify the main themes (hereafter referred to as concepts), the relationship between themes, and their frequency (Heberling et al., 2019). Concepts are defined in ACAs as collections of correlated words that encompass a central theme (Nunez-Mir et al., 2016). A length of two sentences per statistical individual (block) has been set up. We targeted concepts related to the translocation of eels, as well as the relationships between translocation, eel traits, and ecological processes. The ACA returned conceptual clouds or maps of related concepts. We calculated the probability of association between concepts in the same text segment (likelihood).

2.4. A comprehensive narrative review method

The quantitative approach to the literature review helps demonstrate the nature and diversity of research topics amenable to provide essential evidence for those concerned with the internal and external validity and likely effects of eel translocation in different settings. However, it provides little information on how available research approaches, their theoretical perspective, empirical protocols and results can support the evaluation of the efficiency of complex translocation interventions. We complemented the quantitative analysis with a qualitative analysis focused on the main themes or sub-themes identified from the literature most studied ecological processes (ACA concepts) related to translocation (see details in Fig.2.2). To this aim, we compiled a smaller corpus of 23 articles drawn from the large corpus (Appendix 4), based on the following criteria:

- translocation actions such as “restock*”, “translocate*” or “stock*” are mentioned in the title or abstract
- a whole section of the article is dedicated to the implications of the results for eel management policies
- the article addresses translocation from a conservation perspective

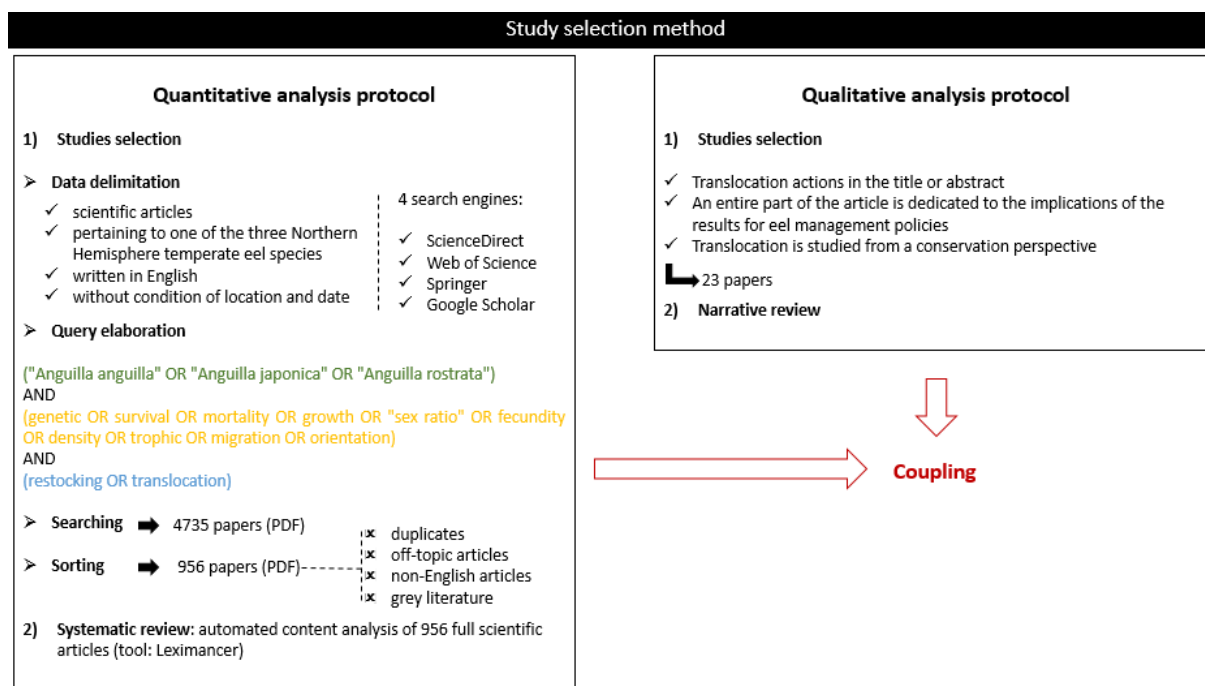


Figure 2.2: Coupled quantitative and qualitative methodology.

3. Results

3.1. Content analysis

3.1.1. Bibliometric

The corpus initially counted a total of 4,735 research articles. After removing duplicates, off-topic articles, non-English articles and grey literature, it was reduced to 956 articles published between 1933 and 2021 (supplementary material S1.2). The publication numbers increased over time, in line with the general trend in the overall scientific literature.

The corpus spanned 238 different journals covering a wide range of fields, all generalist journals on ecology, aquaculture, fish biology, or aquatic ecology. The diversity of scientific journals also increased over time. In the early 1980s, the journal *Aquaculture* became the leading journal for eel research, and it still remains a dominant journal (Fig. 2.3). In recent years, the cumulative number of publications in environmental sciences and ecology journals has by far exceeded that in aquaculture journals.

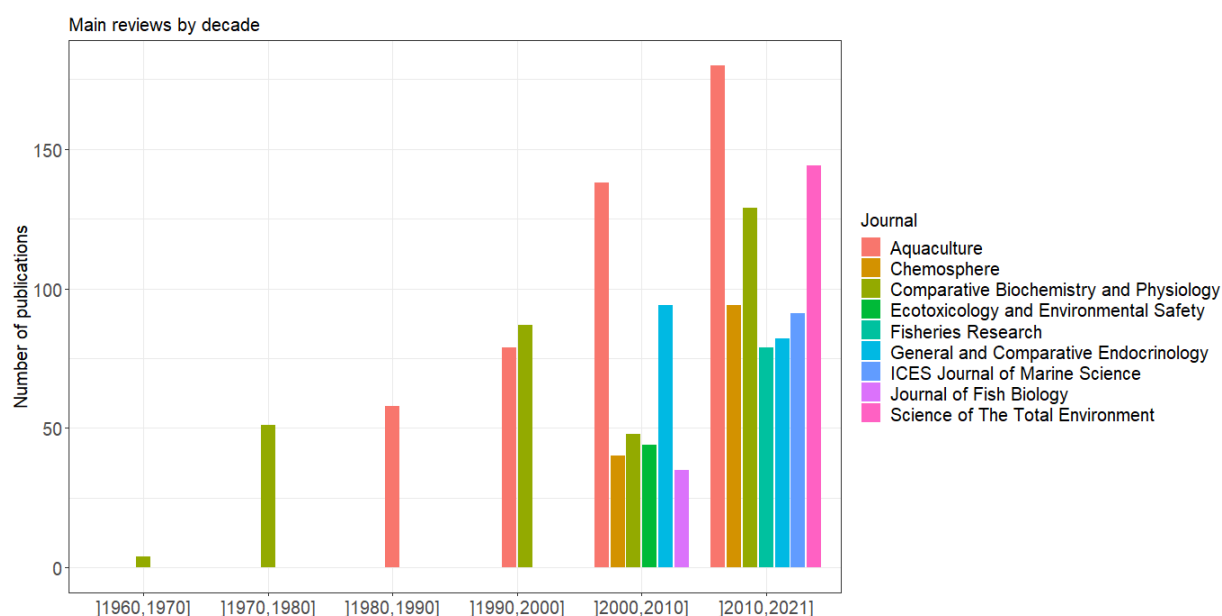


Figure 2.3: Main journals by decade (journals in which 95% of the scientific articles included in the literature review were published, per decade).

3.1.2. Major research streams

A total of 153 concepts were identified in the ACA (supplementary material S1.3). The “eel” concept was identified as a central concept in the corpus (supplementary material S1.5 and Fig. 2.4). Among the most studied themes, eel translocation featured in the concept “restocking” (supplementary material S1.5) which was very frequent throughout the entire corpus, and appeared 4,130 times (5% of concept occurrences in the corpus) (supplementary material S1.5). This result might seem obvious since "restocking" is part of the list of keywords used to select the articles, but some other keywords of this list, such as "fecundity", "trophic" or "orientation" do not appear in the list of concepts. The keywords chosen to feed the query do not necessarily drive the conceptual analysis.

At first, the keyword “translocation” didn’t appear in the results as a concept, contradictory to “restocking”. To deepen the analysis, we added 5 concepts related to the keyword “translocation” (“translocation”, “translocated”, “translocate”, “translocates”, “translocating”) and merged them manually with the concept of “restocking” (supplementary material S1.3).

“Restocking” is directly connected to the concepts of “yield”, “biomass” and “commercial” on the concept cloud (supplementary material S1.6) which featured on the map of related concepts, in a pool of concepts associated with “exploitation” and “management of eels”, such as “stocks”, “anthropogenic”, “conservation”, “fisheries” and “management” (Fig. 2.4, supplementary material S1.6, dark green). Overall, the central “eel” concept was associated with a wide variety of concepts relating to migration and reproduction (artificial or not) (Fig. 2.4, supplementary material S1.6, red, orange and dark blue), to life history traits such as growth or sex ratio (Fig. 2.4, supplementary material S1.6, orange), and to the quality of the eel’s living environment, especially in terms of contamination (Fig. 2.4, supplementary material S1.6, turquoise).

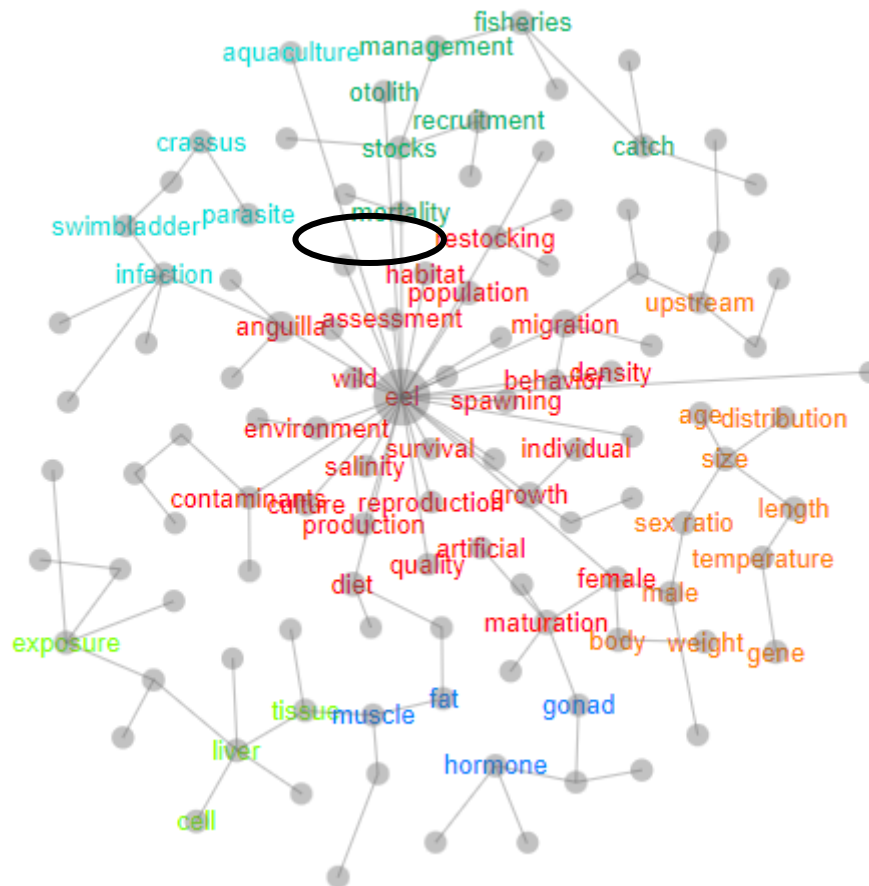


Figure 2.4: Concept cloud (Gaussian distribution to facilitate the reading). For the sake of clarity, a list of concepts related to habitats, species and development stages was removed: European; glass; silver; japonica; rostrata; freshwater; larvae; river; yellow; estuary; elver; coast; egg; trout; sea; lake; salmon; marine; juvenile; adult; ocean; lagoon; continental; seawater; brackish; catchment; leptocephali; inland; young; American; European; Japanese; and Sargasso Sea. This conceptual map represents 50% of the most relevant concepts over the 120 remaining concepts and how they are related. The themes are heat-mapped, meaning that warm colors (red, orange) denote the most important themes, while cool colors (blue, green) denote less important ones (Leximancer User Guide).

Within the corpus, the most studied developmental stage was glass eel, followed by silver eel (supplementary material S1.5).

The three species of interest for the present study emerged from the ACA output as distinct concepts (“European”, “rostrata”, “japonica”) with a relevance greater than 5% (supplementary material S1.5). This finding demonstrated the value of focusing the assessment of eel translocation efficiency on this list of species. Yet the three species did not receive the same

attention in the research. Concepts associated with the European eel were the most diverse, ranging from reproduction to life history traits, habitats and their degradation, aquaculture, and restocking. The concepts associated with the other two eel species were less varied. The American eel was mostly associated with concepts relating to life history traits, and the Japanese eel was mostly related to the concept of artificial reproduction (supplementary material S1.7).

The concepts most frequently associated (over 5% likelihood) with “restocking”, were “yield” (23%) and “farm” (19%) (Fig. 2.5). The association with the concepts “wild” and “conservation” ranked 11th and 12th (11% likelihood) (Fig. 2.5).

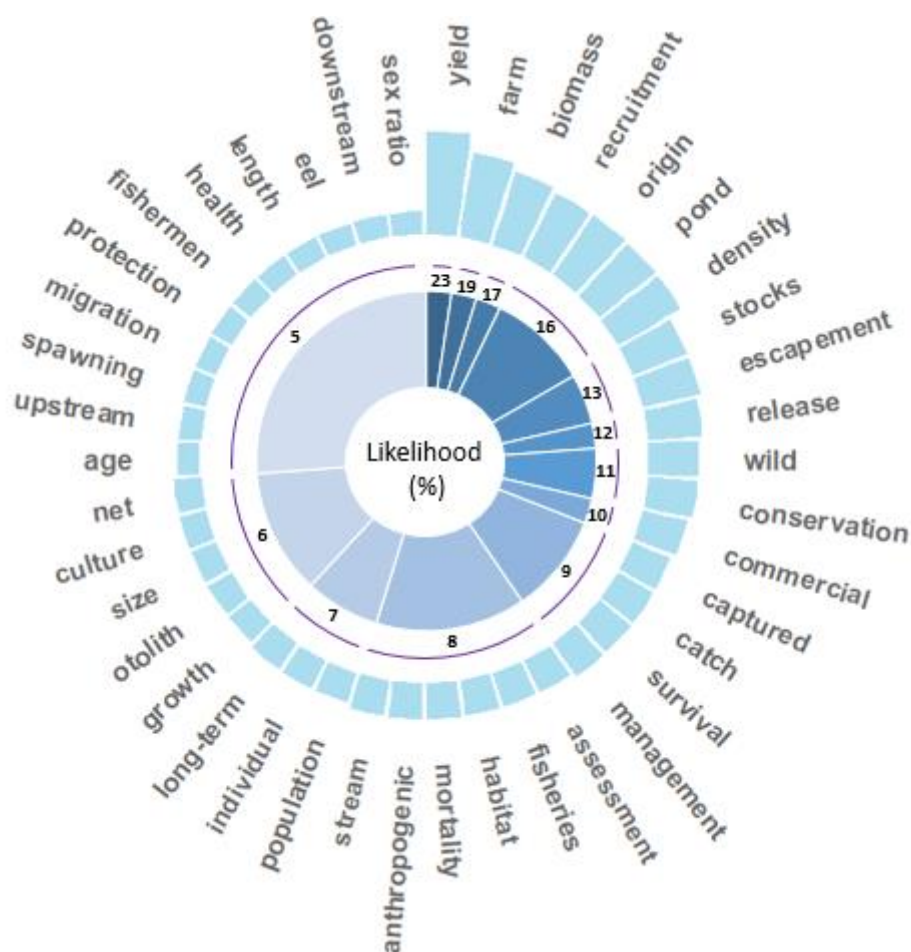


Figure 2.5: Main concepts associated with the concept of “restocking” (with a likelihood \geq 5%) revealed by the ACA.

3.1.3. Key themes and representative articles

Based on the concepts most closely associated with eel translocation in the ACA (concept of “restocking”) (Fig. 2.5), we decided to focus the narrative review on four main associations which captured four key scientific debates surrounding the ecological efficiency of eel translocation (Fig. 2.6). The association of “restocking” with the concepts of “survival” (9% likelihood), “mortality” (8% likelihood), “growth” (6% likelihood), “size” (6% likelihood) and “length” (5% likelihood) (Fig. 2.5) captured the debate surrounding the relative survival of translocated eels compared to wild eels. The association of “restocking” with the concepts of “health” (5% likelihood), “habitat” (8% likelihood), “density” (16% likelihood) and “sex ratio” (5% likelihood) (Fig. 2.5) captured the debate surrounding the mismatch between phenotype and habitat. The association of “restocking” with the concepts of “migration” (5% likelihood), “escapement” (13% likelihood) and “downstream” (5% likelihood) (Fig. 2.5) captured the debate surrounding the migration success of translocated eels. The last scientific debate included in the narrative synthesis was the emerging research issue surrounding translocated eels’ interaction with the aquatic habitat community, even though it was not prominent in the ACA.

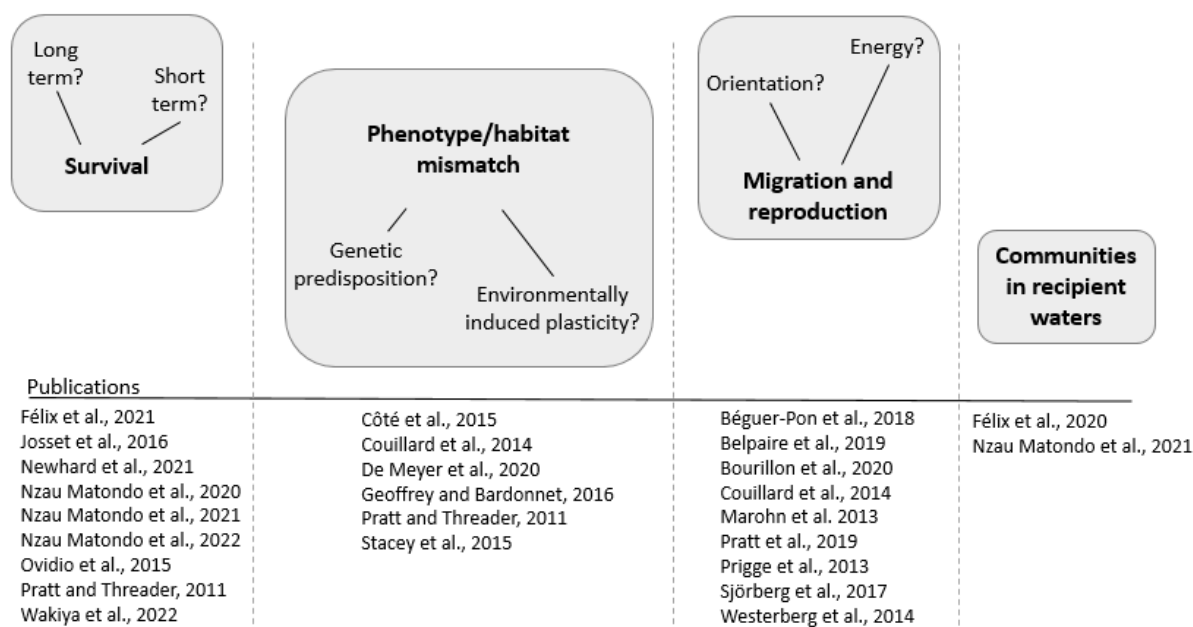


Figure 2.6: This figure summarizes the main research issues associated with each ecological process that have been intensely debated in the literature. For each theme, it associates the reference works on which we based ourselves to determine the state of the debate.

3.2. Insights from narrative review

3.2.1. *The growth and survival of translocated eels compared to wild eels*

Only recent articles (>2020) addressed the survival of translocated eels throughout their growth phase up to the silver stage within a reintroduction context (Newhard et al., 2021; Nzau Matondo et al., 2022). Looking at the short term, translocated eels' survival and growth rate varied and mostly depended on the translocation protocol, whether for reintroduction or for reinforcement (Pratt and Threader, 2011; Ovidio et al., 2015; Josset et al., 2016; Nzau Matondo et al., 2020; Felix et al., 2021; Nzau Matondo et al., 2021). The survival rate can be as high as 95% (Nzau Matondo et al., 2020). The death of translocated eels occurs during fishing, stalling, tagging, transport and release (Josset et al., 2016). With the exception of Josset et al. (2016), none of the authors took into account fishing mortality. Overall, studies found a high short-term survival for translocated eels in the case of tailored protocols. Only one article focused on an experimental setting, comparing natural mortality with the mortality of translocated eels in a context of reinforcement. This showed that wild eels performed better than translocated eels in terms of survival and growth (Wakiya et al., 2022). Due to a lack of information, our literature review on survival could not conclusively determine whether translocated eels had a higher survival rate than their naturally recruited counterparts until they reached their reproductive stage. However, the results shown in this group of papers suggested that translocation carried out for reintroduction achieves better survival and growth rates among the translocated eels than translocation carried out for reinforcement.

3.2.2. *A mismatch between phenotype and habitat*

The interaction between the eel genome and the environment shapes phenotypic diversity in eels, including sex (Geoffroy and Bardonnnet, 2016), growth rate, and ultimately age and length at maturity (Couillard et al., 2014; Côté et al., 2015; Stacey et al., 2015). The consensus in the reviewed literature was that early-stage environment-genome interaction, including local density dependence effects, was a significant driver of phenotype induction (Geoffroy and Bardonnnet, 2016). Many empirical observations and experimental studies supported the hypothesis that sex is determined at an early life stage by the local eel density (Geoffroy and Bardonnnet, 2016). High densities were found to induce a higher proportion of males and the

clustering of translocated eels before release could trigger a male sex induction (Geoffroy and Bardonnet, 2016). At the silver stage, eels translocated from coastal habitats to distant upstream habitats exhibited the phenotype observed in their habitat of collection (i.e. small size at maturity, male-biased sex ratio) rather than the phenotype observed in their habitat of release (Couillard et al., 2014; Stacey et al., 2015). Studies concerned with the spatial selection of phenotypes and the environmental sex determination of temperate eels all warned about the interaction between translocation and eel phenotype induction (Geoffroy and Bardonnet, 2012; Côté et al., 2015; Stacey et al., 2015). The observation of male eels in distant upstream freshwater habitats after eel reintroduction supports the hypothesis of a sex ratio biased by translocation (Pratt and Threader, 2011). Apart from sex, the bias in other morphological traits – such as head shape and body size – induced by translocation place restocked eels at risk of maladaptation (De Meyer et al., 2020). To avoid this, some authors further recommended a precautionary approach restricting the use of translocation to a trap and transportation process to help eels cross aquatic obstacles within the same river basin (Côté et al., 2015; Stacey and al., 2015).

3.2.3. Translocated eels' migration capacity compared to wild eels

Temperate eels require sufficient energy stores and adequate navigation abilities to complete their journey to the spawning areas. Whether translocated eels have these assets at the silver stage has long been debated. Studies using tagging methods observed the successful migration of translocated silver eels towards their spawning areas, showing that at least part of the translocated individuals were able to adopt a regular migration behavior within the framework of reinforcement actions (Westerberg et al., 2014; Sjöberg et al., 2016; Béguer-Pon et al., 2018). These studies did not estimate the proportion of translocated eels effectively contributing to reproduction. Compared to wild eels, translocated eels exhibited a delayed migration behavior, which depended on the release location (Prigge et al., 2013; Sjöberg et al., 2016). This delay raises questions regarding the ability of restocked eels to reach their spawning areas in time for the spawning event (Prigge et al., 2013).

Moreover, the physiological capacity of translocated eels to complete the migration journey was called into question. When translocation protocols involved the release of eels into freshwater habitats, results suggested that translocated eels did not store sufficient energy to migrate (Marohn et al., 2013; Couillard et al., 2014). Moreover, they produced smaller females

due to maladaptation, and were more prone to infection by a parasite that would impair their migration (Pratt et al., 2019) and to being adversely affected by contaminants (Belpaire et al., 2019; Bourillon et al., 2020).

3.2.4. *The impact of translocation on recipient ecosystems*

The question of the ecological effectiveness of eel translocation from a community ecology perspective was the last research issue we identified as an emerging debate in eel conservation. Only recent studies investigated the role of translocated eels as an interactive component of the aquatic community of their habitat of release (Félix et al., 2020; Nzau Matondo et al., 2021). These studies compared the composition of the aquatic community in a tributary of Mondego River before and after the release of translocated glass eels (Felix et al., 2020) and in several tributaries of Meuse River for three years after the release of translocated glass eels (Nzau Matondo et al., 2021). The results showed that the fish community was unchanged after release and that the invertebrate community became more diverse. However, these two localised case studies alone cannot produce conclusive evidence regarding the benefits of eel translocation for aquatic biodiversity or aquatic community functioning. Moreover, the Belgian study suggested interspecific competition between translocated eels and brown trout (*Salmo trutta*).

4. Discussion and conclusion

The present review showed that there is still considerable room for improvement in the evaluation of the effectiveness of eel restocking for conservation purposes. There is a lack of documented comparative studies on the survival, reproduction, and offspring survival of restocked and wild eels (Table 2.1). This is partly due to the impossibility of accessing the field to evaluate the reproduction success of eels in the open ocean. The efficiency of eel translocation as a conservation measure can therefore only be evaluated based on biological and ecological processes observed during the eels' continental phase. Thus, in order to improve our knowledge on how, when, where, and to what extent the translocation of eels could be implemented, we have highlighted a number of knowledge gaps regarding the effectiveness of eel restocking that warrant further study to support eel conservation (Table 2.1). Moreover, we have provided a valuable body of evidence for decision making in a conservation policy-making or resource-management context.

This review highlights several key points for both conservation policy making and research on the translocation of temperate eel species. Coupling a systematic review with a narrative review allowed for an exhaustive, reproducible and rigorous analysis of the scientific literature on the efficiency of eel translocation. While the systematic review identified the research topics associated with translocation, the narrative review provided an in-depth analysis of the main debates surrounding the research issues relating to the efficiency of translocation as a conservation measure. The consensus and research gaps revealed in this analysis were summarized (Table 2.1). A potential publication bias cannot be excluded, which is the under-representation of negative results in the literature, namely eel restocking failures in our case (Cochran-Biederman et al., 2015; Resende et al., 2020). However, the large number of articles reviewed (956) should limit the importance of this bias for the analysis. The choice to focus on the efficiency of translocation for the three Northern Hemisphere temperate species did not restrict the analysis of translocation efficiency, as the literature on other eel temperate species (*A. reinhardtii*, *A. australis*, and *A. dieffenbachii*) is very scarce and is mostly concerned with fisheries issues (Beentjes et al., 2006).

Table 2.1: Main consensus and research gaps

Consensus	Research gap
Individual scale	
<ul style="list-style-type: none"> • Short- and medium-term monitoring • Restocking interferes with natural selection processes • Migration behavior 	<ul style="list-style-type: none"> • Long-term monitoring • Comparison of survival and growth with those of wild eels • Oceanic migration • Impact of delayed migration on reproduction • Fecundity of restocked females
Population scale	
<ul style="list-style-type: none"> • No depletion of the gene pool (panmixia) • Random dispersal of larvae • Influence of density on traits, including sex ratio 	
Community scale (emerging debate)	
	<ul style="list-style-type: none"> • Predation of restocked glass eels • Effect on communities after restocking

4.1. Implications for research

From a conservation perspective, the long-term monitoring of translocated eels' survival and growth provided a valuable contribution to the research (Pratt and Threader, 2011; Ovidio et al., 2015; Josset et al., 2016; Nzau Matondo et al., 2020; Félix et al., 2021; Newhard et al., 2021; Nzau Matondo et al., 2021; Nzau Matondo et al., 2022; Wakiya et al., 2022). However, the studies were mostly focused on translocated eels exclusively, rather than on the comparison of naturally recruited eels and translocated eels. The evaluation of translocation efficiency from a species conservation perspective was more effectively measured when looking at the outcomes of studies on silver eel migration. The emerging issue of the role of translocated eels in the aquatic community of their habitat of release evidenced a shift in perspective in research on the efficiency of eel translocation. The issue of eel as an umbrella species is also implemented in an ecosystemic conservation framework (Itakura et al., 2020).

A strict evaluation of the ecological efficiency of translocation should directly compare translocated eels with their wild counterparts at the fishing site and the release site (in the case of reinforcement action). Comparisons of wild and translocated eels in a production objective address only partial measure of the fitness (Bisgaard and Pedersen, 1991; Pedersen, 2000; Lin et al., 2007) but these studies do not allow to address the comparison in a conservation perspective since it has been carried out in closed habitats. The identification of translocated eels among migrating silver eels suggested that translocated eels were indeed able to survive until the pre-maturation silver stage. Short-term studies found highly variable survival rates of translocated eels, reaching up to 95% (Nzau Matondo et al., 2020). Other older studies reported much lower survival rates, with less than 80 % survival in the Commachio lagoon (Rossi et al., 1988). The natural mortality of eels is quite low, most likely due to the eel's exceptionally low energy-consuming metabolism (Lin and Sun, 2013). Compared to naturally recruited eels, translocated eels would have to survive fishing, handling, marking, transport and release in a habitat they did not choose (Josset et al., 2016). Whether the addition of such anthropogenic stresses led to a lower mortality of the restocked eels than that of the naturally recruited individuals is quite doubtful. Altogether, the literature offered little demonstration that translocation provided a survival advantage for eels in wild habitat contexts.

Translocation was found to interfere with the genome-environment relationship in eel, resulting in phenotype inconsistencies in the habitat of release, bias in sex ratios, or mortality. At population level, the consequences of phenotype manipulation through translocation remained

unclear, but placed translocated eels at risk of a lower fitness than wild eels, as many authors noted.

Although we did not discuss the different translocation scenarios, from an ecology/evolutionary biology perspective, the more advanced the translocation stage, the more disruption there will be to selection processes. For example, the scenarios involving long storing in artificial environments or yellow eel translocations resulted in strong phenotype/habitat mismatches (Verreault et al., 2009).

Where somatic growth, infection, and contamination load were determined by the ambient environment, the habitat of release seemed to be a significant factor influencing the fitness of translocated eels (Belpaire et al., 2019; Bernotas et al., 2020; Nzau Matondo et al., 2021). Moreover, there is a direct correlation between fat content, body length and fecundity in female eels (Durif et al., 2006). One proxy of fitness in eels is somatic size and fat reserve amounts, two key drivers of success in oceanic reproductive migration (migration and maturation processes). In the present review, available results on translocated silver eels showed that they had a shorter body size and a lower fat content than their naturally recruited counterparts, suggesting that they had attained a lower fitness level at the silver stage.

In the present review, the migration behavior of translocated eels was found to be similar to that of wild eels. However, we did not find any estimate of the proportion of translocated eels that migrated successfully with their wild counterparts. Several studies suggested that eels used their magnetic sense to imprint the orientation of their return migration journey (Durif et al., 2013; Cressi et al., 2019), which would entail that translocated eels lacking this imprinting are at risk of unsuccessfully mapping their migration path. The schooling behavior of silver eels (Burgerhout et al., 2013), whereby silver eels of different origins mix, could foster the migration behavior of translocated eels. Social cues were already found to promote upstream migration behavior in eels (Podgorniak et al., 2016). These social cues could compensate for the lack of magnetic imprinting in translocated eels. In turn, this suggests that translocated eels have to mix with wild eels in order to develop a suitable behavior. Research gaps still remain in the evaluation of the relative reproductive success of translocated eels in the spawning area and the subsequent survival of their offspring. The study of eel biology in the marine environment remains incomplete. The only potentially useful information available on migration journeys comes from a satellite tagging study, where silver eels with the lowest fitness levels (size and

fat) leaving continental waters were found to be most prone to predation in the open ocean (Wahlberg et al., 2014).

The benefits of eel translocation for the conservation of eel in aquatic communities is an emerging topic in the scientific literature, with research showing that the introduction of eel in eel-free habitats could increase the biodiversity of the invertebrate community and does not induce changes in the fish community (Felix et al., 2020). There is a knowledge gap in the evaluation of the benefits or drawbacks of eel translocation for the aquatic community. At a smaller scale, an earlier study had already evaluated the benefits of American eel reintroduction to enhance the population of freshwater mussel (*Elliptio complanata*) (Galbraith et al., 2018). This study showed that the reintroduction of eel as a host for mussels was beneficial to mussels, thus producing conservational benefits for eel and mussels. Most of the knowledge on the role of eel as a predator comes from studies published between the 1960s and 1980s (Dekker and Beaulaton, 2016). Aquatic communities have undergone profound changes since then, which are reshaping aquatic communities' interaction webs (Sommerwerk et al., 2017). Previous studies had focused on eel predation on endangered crayfish (Schulz et al., 2005) and salmonids eggs (Mann and Blackburn, 1991). European eel had been considered as officially harmful (Dekker and Beaulaton, 2016) and was destroyed in salmon streams until the 1980s. The dominance of invasive species was observed in contemporary aquatic communities (Sousa et al., 2011), invasive species which are either potential predators (*Silurus glanis*) or potential prey for eels (invasive crayfish). Although the translocation of eels was advised to control invasive crayfish species (Aquiloni et al., 2010), the efficiency of the re-introduction of eels into invasive species-dominated habitats was not evaluated. Moreover, the risk of introducing new pathogens in recipient waters should be considered. Even though intraspecific transmissions of pathogens has been studied, as a case study for *A. crassus* infection (Pratt et al., 2019), interspecific infections were not mentioned in the scientific literature.

In order to achieve a broader understanding of the eel's role in ecosystems, more knowledge on the role of translocated eels as prey is also needed, although some studies have already addressed glass eel predation (Miyake et al., 2018) and silver eel predation (Beguer-Pon et al., 2012; Wahlberg et al., 2014). There is an overall lack of evaluation of the consequences of eel introduction in eel-free habitats, or habitats with a low eel density. The introduction of animals or their reintroduction can have unintended consequences that may hinder conservation efforts (Pearson et al., 2022) and call for a careful evaluation of the recipient community's interaction web to identify and mitigate unintended outcomes. The interaction between eel translocation

and global warming was not specifically addressed in the literature gathered for the present review, suggesting that there was a knowledge gap on this topic. The fact that eels do not reproduce in recipient waters makes the effect of global warming difficult to assess (Drouineau et al., 2018).

4.2. Implications for conservation policy making

The present review yielded contrasting results: while they showed greater translocation efficiency in the context of reintroduction in terms of survival, growth and aquatic community, they conversely revealed greater translocation efficiency in a reinforcement context in terms of phenotype/habitat alignment and migration. The phenotype/habitat mismatch tends to show that eel translocation is not an efficient conservation measure at the scale of the eel's continental life stages (from glass eel to silver eel).

Reintroduction of eels where they were absent resulted in better growth and survival. However, eel-free habitats are often located in the freshwater upstream part of river catchments, where obstacles can impede migration. More generally, translocated eels were most often released in landlocked habitats (i.e. lakes with no outlets for silver eel migration), a choice that is irrelevant from a conservation perspective. The choice of landlocked habitats was initially made either for fishing purposes or within the framework of conservation action to facilitate the monitoring and evaluation of restocking (Pedersen, 2000; Kangur et al., 2002; Simon and Dörner, 2014). However, eels restocked in freshwater habitats and/or landlocked habitats may compete resulting in reduced growth rates, lower food production, and subsequent lower habitat carrying capacity, all obstacles to silver eel migration. This disadvantage of landlocked habitats may be offset by the storage of qualitative fatty acids in freshwater habitats (Parzanini et al., 2021). In order to overcome imprinting issues, restricting action to “trapping and transporting” was highlighted as a more valuable practice than translocation. However, releasing eels above manmade obstacles to migration has to be coupled with assistance for downward migration to their spawning areas. Moreover, transferring eels into upstream habitat may bias the sex ratio. The present review did not find that translocated eels had a fitness advantage over wild eels. When translocation actions may allow the optimisation of one part of eel fitness component at a time (i.e. survival, migration, etc.) it is to the detriment of other life traits, which means that fitness cannot be optimised as a whole in the frame of translocations actions.

In the polemics around translocation actions and more specifically for eels, two main arguments arose (emergent). The pros of eel translocation insist on the fact that eels are transported to better quality habitats and avoid mortality but the present study showed that this fitness advantage was not supported in the scientific literature. Another argument is that the translocated eels are taken as a “surplus”, in habitats of limited carrying capacity and hence are saved. The surplus argument is doubtful in a context where glass eel recruitment has dropped dramatically, above 90% from 1980’s values for European eel (ICES, 2016). The obstacles inducing local surplus is yet an issue of interest. But translocation action in this case would be restricted to “trap and transport” actions, with the same difficulties previously mentioned.

Beyond the framework of conservation efficiency, eel translocation was initially guided by economic perspectives. The practice of eel translocation is still largely driven by production objectives within the framework of fishery and aquaculture. The ambivalence surrounding eel conservation stems from the fact that eel is still an exploited species with high economic value. Thus, for the three Northern hemisphere temperate species, glass eel fisheries were still allowed within conservation management plans whereas partial or total fishing bans were implemented (Fishery Management Report No. 36 of the Atlantic States Marine Fisheries Commission; Interstate Fishery Management Plan for American Eel April 2000; Décret n° 2010-1110 du 22 septembre 2010 relatif à la gestion et à la pêche de l'anguille; The Bureau of Fisheries of People’s Republic of China et al. 2014).

In the case of European eel, translocation actions are undertaken by commercial fishery actors. In Japan, where the Fisheries Act has mandated that inland water fishery cooperatives which catch eels in rivers and lakes increase their eel populations, these cooperatives typically restock eels to fulfil this obligation (Kaifu 2019). As far as we are aware of, there are only few translocation successes reported in the scientific literature for endangered species, either exploited, such as The Golden lion tamarin (*Leontopithecus rosalia*) (Kierulff et al., 2012), or not exploited, such as the threatened Clouded Apollo butterfly (*Parnassius mnemosyne*) (Kuussaari et al., 2015). This tends to show either that translocation efficiency as a conservation action might be underestimated or that this kind of measure mainly fail considering that failures are less published. However, success was achieved for translocations of several threatened species in the U.S under a conservation framework (Novak et al., 2021). The same study provided evidence that translocation led with economic or recreational frameworks did not fulfil the conservation objectives and failed. This calls for an urgent change of perspective regarding translocations of eels in the objective of conservation.

Eel translocation actions are often designed as mitigation actions (at least for *A. anguilla* and *A. japonica*) to offset fishery activities. “Because mitigation releases are economically motivated, outcomes may be less successful than those of releases designed to serve the biological needs of species” (Germano et al., 2015). The gap in the evaluation of the socio-economic mechanisms underpinning the ambivalence of eel translocation as a conservation measure still remains, and warrants closer study.

To conclude, translocation actions, also known as “restocking” or “stocking”, seems ultimately doubly inefficient. First, they do not increase the catch biomass at the eel population level (Dekker and Beaulaton, 2016). Second, in the present “argumentum absurdum” reasoning, we showed that translocation actions resulted in the fact that fitness of eel cannot be cumulatively optimised along the part of life cycle that was accessible in the scientific literature (mainly continental life stages) and were even sometimes inefficient or harmful (Novak et al., 2021).

SECOND CHAPTER

Conserving threatened eel species with policy instrument mixes in Japan: what's consumers' pro-environmental orientation got to do with it?

A version of this chapter is being prepared for submission to Ecological economic¹

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Conserving threatened eel species with policy instrument mixes in Japan: What's consumers' pro-environmental orientation got to do with it?

Abstract

Threatened eel species have been highly consumed in Eastern Asian countries, including Japan, in which eel is traditionally consumed broiled (“*kabayaki*”) during summer. Consumers are therefore part of the eel species conservation issue and including them to the decision-making process would be a way to avoid public resistance when environmental improvement objectives are translated into political solutions. We therefore performed a discrete choice experiment method in order to investigate policy-mix schemes promoting eel conservation that could win the support of Japanese citizens. This includes supply-side instruments, such as fighting against illegal trade by controlling imports or developing research on artificial eel reproduction, and demand-side instruments based on regulatory mechanisms, such as increasing the “*kabayaki*” price, reducing the consumption quantity (coercive policy), raising public awareness or substitution a part of eel consumption with other species (non-coercive policy). Our empirical investigation was based on the preferences of 1,088 individuals who declared consuming eel products. A latent class logit model has been applied, allowing us to distinguish three different classes among the Japanese eel consumers, based on heterogeneous preferences. Analysis revealed that for now, individual knowledge and environmental concerns play an ambiguous role for the preferences concerning ambitious policy mixes (i.e. including coercive policy instrument). Our results also revealed that the most pro-environmental respondents in their policy mixes choice are positive about developing research on artificial reproduction. We found evidence that people who behave pro-environmentally would be more supportive of the introduction of more restrictive policies. In addition, people are more likely to support policies and behave pro-environmentally when their intrinsic pro-environmental motivation and concern is strong. Based on these results, policymakers might increase consumers' engagement by making it easier for people to improve their intrinsic pro-environmental motivations and values by developing and improving environmental education.

1. Introduction

As part of the global biodiversity crisis, we are witnessing a strong decline in the levels of recruitment of the Northern temperate eel (*Anguilla* spp.) population throughout its distribution area (Righton et al., 2021). The IUCN has classified the species as endangered (American eel *Anguilla rostrata* and Japanese eel *Anguilla japonica*) or critically endangered (European eel *Anguilla anguilla*) (Jacoby et al. 2017; Pike et al. 2020a & 2020b). Yet, *Anguilla* spp. are globally exploited at the various stages of their life cycle for consumption. The juvenile glass eels in particular are caught for the aquaculture industry. Since the European eel was listed in Appendix II of the Convention on International Trade in Endangered Species of Wild Fauna and Flora (CITES) in 2007, its export outside the European Union is prohibited in 2010. While the data from official statistics do not allow for tracing illegal flows, recent studies applying molecular techniques attest to the use of European eel on gastronomic and food markets worldwide (Nijman and Stein, 2022). The increase in the global demand for eel products prompted the expansion of a lucrative black market for trade in young and wild-caught eels (Kaifu et al., 2019). Anguillid eel species are thought to be exposed to a suite of pressures that are not limited only to exploitation (Jacoby et al. 2015, Drouineau et al. 2018, Righton et al. 2021), and a holistic management approach covering habitat degradation, water abstraction, parasites and diseases, and climate change is required (ICES 2022; Kaifu et al. 2021). Nevertheless, further improvements of the management system for eel exploitation in Japan, one of the global demand centres, will help achieve the conservation and sustainable use of Anguillid eel species (Scheffers et al., 2019).

The international trade of eel products has been driven mainly by demand from Japan, with eel being an important part of Japanese culture and food resources. Festivals such as the “*Doyo no Ushi*” (Eel Festival) have been an integral part of Japanese culture for centuries. Eels are mainly consumed as “*kabayaki*” (Kaifu et al., 2019), a traditional processed dish from the Edo period. While Japan is considered the historical consumer of eels, demand for eel processed products outside Japan seems to have increased recently. Nowadays, half of the Chinese aquaculture industry's production supplied its domestic market (Sakurai and Shibusawa, 2021). Similarly, while eel is not part of the local cuisine in Indonesia, processed eel products are currently being developed and promoted in the country (Muthmainnah et al., 2020). It appears that approaches to increase consumer responsibility to address conservation of threatened species, together with

the development of programs to address illegal trade of wild eels, have to be adequately explored, at global scale and specifically in Japan.

This study is the first endeavour to conduct an economic valuation to identify socially appealing policy interventions for the conservation of threatened eel species in Japan. Policy interventions to protect a threatened species can also provide consumers as citizen with a range of values in addition to current consumption values (Bartczak et al., 2016; Lew et al., 2010; Lew and Wallmo, 2017; Wakamatsu et al., 2018; Gong et al., 2020; Mzek et al., 2022). The formulation and implementation of conservation policies and of policies targeting fish species more specifically are inextricably influenced by the support of the Japanese public (Fujino et al., 2017; Wakamatsu and Managi, 2019). If citizens feel excluded from the decision-making process, the implementation of these measures often comes up against public resistance when environmental improvement objectives are translated into political solutions.

We therefore apply the discrete choice experiment (DCE) method to investigate policy-mix schemes promoting eel conservation that could win the support of Japanese citizens. The DCE method involves presenting respondents with several scenarios characterized by various attributes – in the present case a specific combination of different instruments –, and asking them to identify their most preferred scenarios. DCEs have the benefit of allowing for all attributes of a scenario to be considered simultaneously, thereby forcing respondents to weigh up the different policy instruments rather than consider each one in isolation. As such, the DCE method constitutes a suitable empirical approach for determining relative preferences among different policy instruments for eel conservation, broken down into different economic mechanisms, as well as relative preferences regarding their combination.

Recent studies (Wakamatsu and Managi, 2022; Hirokawa and Thompson, 2023) have shown that Japanese consumers have some interest in sustainable seafood consumption. However, voluntary behaviour changes to protect an endangered species is inextricably linked to the social psychology of green consumerism (Hori et al., 2020). Much of the psychological research on consumer pro-environmental behaviour shows that while a majority of people seem to adhere to pro-environmental beliefs, few are willing to permanently give up the low price, convenience and ease of "non-green" products (Sachdeva et al., 2015). In this study, we consider that the individual is seen both as a citizen, who might support a policy that can be effective in order to reduce demand pressure and illegal trade and thus better preserve the species, and at the same time, as a consumer, who sees opportunities and motivations to change his own behaviour

(Merten et al., 2022). Our empirical investigation is therefore based on the preferences of 1,088 individuals who have declared consuming eel products. Further, the sample was equally distributed across the eight Japanese regions, and obtained through an online survey conducted in February 2023.

We have applied an exploratory latent class logit model (Hess, 2014; Amaris et al., 2021), so as to let the data collected tell their story about the structuration of individual respondent preferences for eel conservation with policy instrument mixes and the underlying pro-environmental aspects. Identifying classes of preferences for policy mixes supporting eel conservation helps advance our understanding of the conditions under which a combination or overlap of instruments constitutes a win-win scenario to address conservation and consumption issues. Our study also provides a deeper look into the heterogeneity in individual preferences. We explore in particular the consumer characteristics associated with an individual being more likely to belong to a particular preference group. Previous studies on consumers' preference for sustainable fish products have revealed the influence of respondents' sociodemographic characteristics and environmental knowledge (Bronnmann and Asche, 2017; Risius et al., 2017; Aanensen et al., 2023 to cite but a few). This study adds to the empirical literature by identifying the spill-over effect of other pro-environmental behaviours (Maki et al., 2019). Further, we examine the influence of place of residence, as conservation measures often have an unequal impact (burden and benefit) on rural and urban areas, and according to the geographical distribution of species to be protected (Lew, 2019).

Furthermore, environmental consciousness assessed using the New Ecological Paradigm (NEP) scale was widely applied in the stated preference survey. Several valuation studies on endangered species conservation policy using the NEP scale (Tanner et al., 2021; Choi and Fielding, 2013) highlight that individuals who endorse this paradigm consistently engage in behaviours that align with it. Unlike studies that use NEP scores as a direct predictor in the class allocation model (Bartczak, 2015) or as latent variables (Taye et al., 2018; Aanensen et al., 2023), we here make use of posterior probabilities to compare the average value of NEP scores (for the 15 statements and five value types of the NEP scale) across classes of preferences (Amaris et al., 2021). This allows us to explore how generic environmental concern and ecological worldview relate to the contextual specific pro-environmental behaviours.

The remainder of the paper is organized as follows. Section 2 outlines the survey and introduces the econometric method applied. Section 3 presents the sample characteristics. Section 4 is dedicated to the econometric results. Section 5 concludes and offers policy recommendations.

2. The Japanese context

In Japan, the illegal catching and distribution of glass eels have been considered a major threat to the Japanese eel, a native freshwater eel species in East Asia. For example, during the 2014–2015 fishing season, the reported catch accounted for only 37% of the total volume of glass eels caught in Japan's domestic waters (Kaifu et al. 2019). The remaining 63% (equivalent to 9.6 tons of glass eels) were traded through unlawful means, i.e., IUU (Illegal, unreported and unregulated) fisheries. Additionally, there were 3.0 tons of imported glass eels believed to have been smuggled from a country of origin to Hong Kong and then exported legally from Hong Kong to Japan (Crook and Shiraishi 2015; Kaifu et al. 2019). In total, for the Japanese eel, about two-thirds of the glass eel input into eel farms in Japan in that fishing season have a high probability of being fished and/or traded through unlawful activities.

Recently, the Fisheries Act was amended (<https://www.japaneselawtranslation.go.jp/>, 2023), and fines on illegal glass eel fishing in Japan's waters were raised by 300 times (up to 30 million JPY). This amendment will come into force for glass eel fisheries in Japan by December 2023. Moreover, the Act No. 79 (2020) on Ensuring the Proper Domestic Distribution and Importation of Specified Aquatic Animals and Plants (Proper Distribution Act hereafter) was newly promulgated in 2020 and went into effect at the end of 2022 to combat the distribution of products originating from IUU fisheries. The act defined Class I and II for aquatic animals and plants that are particularly vulnerable to IUU fishing; the former includes domestic organisms fished in Japan's waters, and the latter includes organisms that are fished by foreign-flagged vessels under foreign laws. Glass eels are listed as Class I but not as Class II so far, with a three-year moratorium (implementation is expected in 2025). Glass eels that are fished in Japan will be subject to this act, while imports from outside Japan will not.

Regarding the consumption quantity of Japanese eel, China, Japan, South Korea, and Taiwan have limited glass eel input into aquaculture ponds (The Bureau of Fisheries of the People's Republic of China et al. 2014). Even though the limit between the four participants is not legally binding, Japan established a domestic legally binding regulation with the aim of ensuring that glass eel input does not exceed their quota. However, some areas remain to be improved for the

conservation and sustainable use of Anguillid eels. First, glass eels smuggled from the country of origin are thought to be imported into Japan. Second, for the Japanese eel, the Japanese Government controls glass eel input into domestic aquaculture ponds based on 'Common Views' between China, Japan, South Korea, and Taiwan (The Bureau of Fisheries of the People's Republic of China et al. 2014). However, it is argued that the limit has not decreased Japanese eel consumption because the total ceiling of the four participants is about twice as large as the actual glass eel catch (Kaifu et al. 2019). Third, as Anguillid eel species other than Japanese eel have been imported to and consumed in Japan (Gollock et al. 2018), careful consideration should be paid for the other eel species to avoid excessive consumption and/or illegal activities.

Finally, Japan is currently concentrating its efforts on research on artificial reproduction (Hamidoghli et al., 2019). Breeding in captivity might have the potential to bring about a positive impact in reducing glass eel catch. However, the ceiling for the glass eel input between the four participants is limited for “glass eels and eel fries taken from the wild” (The Bureau of Fisheries of the People's Republic of China et al. 2014). Therefore, when captive-bred glass eel is distributed for commercial use, it can serve as a supplement to wild glass eel catch, in other words, wild glass eel catch would not be reduced due to captive-bred glass eel under the present framework. If an appropriate input limit is set based on scientific knowledge, and the eel market faces a shortage of glass eel supply due to more severe restrictions, artificial reproduction techniques can contribute to Anguillid eel conservation by providing an alternative option for eel market. Another way for captive-bred glass eel to contribute to Anguillid eel conservation can be to include them in the input limit.

Pursuing the twofold objective of sustainable use of fish resources and biodiversity conservation requires a combination of supply-side and demand-side instruments (Ring and Barton, 2015; Bouma et al., 2019), so as to reach these objectives as effectively as possible and to target the full range of different pressures on eel species stocks exerted by markets and trade.

3. Choice design and data collection

The discrete choice experiment method (Adamowicz et al., 1998; Louviere et al., 2000) has become particularly prized in environmental valuation studies (Carson and Czajkowski, 2014), particularly for the protection of threatened and endangered marine species (Lew, 2015). The choice experiment methodologies have typically been used – with success – to assess Japanese

consumers' preferences and willingness to pay for fish products with environmental labels (Uchida et al., 2014; Wakamatsu and Managi, 2022), for sustainable seafood products (Hori et al., 2020), and for marine species conservation (Wakamatsu et al., 2018). This study extends the existing literature by investigating Japanese citizens' preferences for policy instruments targeting eel species conservation.

The DCE is a quantitative survey technique designed to elicit individual preferences. Individual respondents are asked to make a number of choices between different hypothetical management/policy scenarios defined by their attributes, with different levels proposed for each attribute. Choice data obtained with the DCE survey are then used to infer the perceived utility of each of these attributes for individual respondents, the trade-offs they make between these attributes, and the overall benefit of the policy scenario. The DCE process follows four steps (Hoyos, 2010): attribute selection and the definition of their levels; experimental design and the construction of the choice sets; questionnaire design and the definition of the sampling strategy; and application of the econometric estimation method for data analysis.

3.1. Policy scenarios' attributes

This study was designed to investigate policy mix-schemes for eel conservation and the trade-offs that Japanese consumers make between different policy instruments. The scenarios' attributes and levels are summarized in Table 3.1. Two public intervention tools are already being promoted but not realized yet to better protect eel stocks: increased control of imported products to trace illegally sourced glass eels, and the development of research to speed up artificial eel reproduction (cf. previous section). The first attribute promotes "Controlling imported products" to combat illegal trade. We assigned two levels to this attribute: weak and strong. The second attribute addresses the importance of research on artificial reproduction for wild eel conservation.

We hereafter consider preferences regarding public intervention instruments particularly geared towards encouraging changes in eel consumption behaviour at national level, which can complement these supply-side policies. Policy instruments are often categorized based on their degree of coerciveness. The environmental policy literature tends to distinguish between non-coercive and coercive policy instruments to encourage behavioural change (Scneider and Ingram, 1990).

A policy can be considered coercive if it targets types of behaviour perceived as particularly difficult to change (Schuitema and Rothengatter, 2010), if it can have a significant direct effect on individual practices, or if it is perceived as potentially infringing on the exercise of freedom (Attari et al., 2009). We therefore investigated relative preferences between three types of instrument targeting change in consumption behaviour, from the most coercive to the least coercive: consumption limits; higher price; consumption of substitute species; and public information. The final selection of policy instruments and their levels was based not only on interviews with stakeholders and experts' advice, but also on the grey and scientific literature.

According to a 2018 Greenpeace study (Greenpeace, 2018), some eel consumers are prepared to reduce the amount of eel they consume and the frequency at which they do so (27.3%), and some would also agree to eat alternative products (26.3%). We thus introduced an attribute for consumption limits in the form of an eel consumption reduction target expected in 2030, set as a percentage of current consumption. The attribute had three levels: 75%, 50% and 25% of current consumption. The reference situation (status quo) was the absence of change.

Furthermore, markets for cultural goods are often characterized by relatively price-inelastic demand, which suggests that interventions that lead to higher market prices may have little or no impact on consumption trends (Chen and Sas-Rolfes, 2021). To explore this assumption in this DCE, one of the attributes was described as an “Increase in the average price for 100g of *kabayaki*” compared to the current price (Yadav et al., 2020). The average price per 100g of this emblematic Japanese dish is referenced in national statistics (<https://www.e-stat.go.jp/>, 2023). In 2021, it was around JPY 1,276. The price increase between each of the four levels of the attribute was made significant enough as to influence choices.

In recent years, academic literature, public policy and conservation organizations are increasingly interested in consumer-targeted interventions that can bring about voluntary behaviour change and reduce demand for endangered wildlife products (Veríssimo et al., 2012; Wright et al., 2015). Considerable effort has been devoted to awareness campaigns targeting demand for products from wildlife species banned from trade (Olmedo et al., 2018). Still according to the 2018 Greenpeace study, a specific demand is emerging among Japanese eel consumers, for more information about the state of eel resources. We therefore introduced a "public information" attribute, in the form either of an information campaign aimed at raising environmental awareness among the general public, or of a product origin and processing certification. Eco-certification is based on an obligation placed on producers to inform

consumers about the traceability and sustainability of their seafood products, to ensure that eel products are processed using environmentally sustainable practices.

Pioneer demand-side approaches consist of introducing and promoting substitutes (Halpern et al., 2021). A "substitute species" attribute was thus presented to respondents: one of three less vulnerable fish species that could potentially take eels' place on "kabayaki" preparations, namely Kindai catfish, Sanma, and Conger eel (<https://www.seafoodsource.com/>, 2023).

Table 3.1: the attributes and levels in the choice experiment



Attribute category	Attribute denomination	Levels
Supply-side instruments	Fighting illegal eel trade by controlling imports	<ul style="list-style-type: none"> • Current level (status quo) • Low increase • High increase
	Developing research on artificial eel reproduction	<ul style="list-style-type: none"> • Yes (status quo) • No
Demand-side instruments based on regulatory mechanisms (coercive policy)	Increasing the average price for 100g of "kabayaki" compared to the current price	<ul style="list-style-type: none"> • ¥1,280 (average price for 100g) • ¥1,410 (10% higher than the current average price) • ¥1,600 (+25%) • ¥1,920 (+50%) • ¥2,560 (+100%)
	Reducing the total quantity of eel consumed in Japan by 2030, compared to the current quantity (around 50,000 tons)	<ul style="list-style-type: none"> • Current quantity (status quo) • 75% of the current quantity • 50% of the current quantity • 25% of the current quantity
Demand-side instruments based on incentive mechanisms (non-coercive policy)	Raising Public awareness	<ul style="list-style-type: none"> • No increased access to information (status quo) • Setting up a label (traceability, origin, farmed or wild) • Setting up a large-scale public awareness campaign
	Substituting a part of eel consumption with other species	<ul style="list-style-type: none"> • No substitute species (status quo) • Kindai catfish • Sanma (Pacific saury) • Conger eel

3.2. Choice experiment design

We offered respondents a series of choice sets with different levels for each policy attribute and determined their WTP for individual eel conservation policy attributes and scenarios. The choice sets were obtained using a D-efficient experimental design, and were generated with the Ngene software (Choice Metric, 2018). With a total of 10 parameters and two alternatives, there had to be a minimum of five choice situations. But as this number of choice sets had to be dividable by not only the number of attributes but also the number of levels associated with each attribute, there had to be a minimum of 12 choice situations. The D-efficiency criterion of the experimental design selected was equal to 0.27. The 12 choice situations were divided into two blocks of six choice cards. Blocks were assigned to respondents randomly (Meyerhoff et al., 2015). Respondents were presented with six repeated choice situations, each including two alternative policy-mix scenarios (Options A and B) and a status quo situation. The inclusion of a status quo alternative (no additional policy intervention, i.e. the current situation) is recommended for the valuation of public goods (Johnston et al., 2017). It can also improve the realism of the choice exercise, and avoids forcing participants to choose one of the proposed public interventions. An example of a choice set is shown in Table 3.2.

The choice experiment method makes it possible to obtain environmental protection preferences directly from individuals. In this framework, individuals are expected to make their choices based on their already existing knowledge and experience. If the individuals taking part in the study are not sufficiently informed about the expected benefits of environmental protection, they will underestimate the importance of the protection policies presented to them (Bergstrom et al., 1990; Hanley and Munro, 1994; Spash and Hanley, 1995). Furthermore, the provision of information improves respondents' understanding of complex evaluation problems (Czajkowski et al., 2016). In other words, in stated preference methods, respondents make their choices with the information provided by the researcher in the survey protocol. In this study, we provided all respondents with detailed information on the eel value chain (from production to consumption), to formally address the surveyed consumers' potential lack of information and knowledge about the eel trade value chain when faced with complex or unfamiliar choices. To ensure that all respondents received identical information before making their choices, the choice-testing protocol began with a video followed by a short-written presentation of all the information needed to reveal preferences.

Table 3.2: example of a choice set

	Option 1	Option 2	Option 3
Global quantity of eels consumed in Japan by 2030, compared to the current quantity (around 50,000 tons)	 25% of the current quantity	 Current quantity	 Current quantity
Partial substitution of eel consumption by other species	 No substitute species	 Sanma	 No substitute species
Development of research about artificial eel reproduction	 Yes	 No	 Yes
Public awareness	 Set up a large-scale public awareness campaign	 No development of the access to information	 No development of the access to information
Fight against illegal eel trade by controlling imports	 Low increase	 High increase	 Current level
Average price for 100g of kabayaki compared to the current one	 2,560¥ (+100% from the average price)	 1,410¥ (+10% from the average price)	 1,280¥ (current average price for 100g of kaboyaki)
Your choice:	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>

The video provided general information regarding the context, starting with the Japanese eel's status as an endangered species and the decline of its population. A talk was then given about eel consumption in Japan: how much is consumed, the eel's origin (fishery, farming, importation), the main dish for which it is used (*kabayaki*), and the average price of eel (Supplementary material S2.1). The respondents could not continue the questionnaire without having finished watching the video. We introduced two control questions after the video in order to verify whether respondents had paid attention to its content. The video was produced with the help of the company The Translation People. The written material detailed the instructions: respondents had to choose between several scenarios, each containing six criteria with different levels. These levels were specified and respondents were asked to indicate which option they found most satisfactory (Supplementary material S2.2).

However, ambiguity may remain regarding the actual impact of the information given to respondents during the survey on conservation policy preferences, as they may be guided primarily by moral and ethical concerns (Rosenberger et al., 2003). This would mean that supplying additional information does not affect individual preferences. Respondents can make their choices irrespective of their prior knowledge of what is at stake, displaying a lexicographic preference: they make their choices based on the alternative that best positions a category of policy instruments (Meyerhoff et al., 2019). As the illegal eel trade is not yet widely known among the Japanese public (Crook and Shiraishi, 2015; Greenpeace, 2018), we wished to test whether the provision of additional information about international legal and illegal eel trade influenced respondents' preferences and hierarchy of policy instruments. A split sample treatment technique was thus developed (Imamura et al., 2020; Imamura et al., 2023). Two versions of the choice experiment protocol were created: one with additional information, and one without. Respondents were randomly assigned one of the two versions, with the treated group receiving the additional information through a longer version of the video presentation (around 30 seconds longer than the short version, which was 2 minutes and 22 seconds long). Particular attention was paid to ensuring that the control and treatment samples had a similar number of observations from each of the regions surveyed.

3.3. Data collection and survey design

A nationwide survey was administered online by a professional survey company, TGM Research, in February 2022. The questionnaire was available in digital format for smartphones. Although the use of the Internet and a video tool opens up a number of debates about work on the perception of biodiversity (Sandord et al., 2016), these tools enabled us to bring together a relatively large sample of Japanese eel consumers spread across the country. The video format also enabled us to communicate more effectively on complex conservation issues, within a fairly short space of time (the two versions of the video lasted 2'22" and 2'45" respectively) and in an illustrative way (Supplementary material S2.1). The questionnaire and online tools were developed in Japanese (Supplementary material S2.1 and S2.2).

One potentially important factor accounting for differences in preferences regarding endangered fish species protection is geography. Within a single country, variation in preferences can be observed across the urban-rural divide, or across different regions (Lew, 2019). The geographical distribution of species' habitat areas also plays a part in the formulation of preferences regarding their preservation (Danley et al., 2021). Data were collected by using a regional quota sampling method. The respondents were pre-screened based on their region of residence and the corresponding town density level. We are aware that the quota sampling method is a non-probability sampling approach. We removed 211 individuals, including respondents who claimed that they did not know about eels, respondents who systematically opted for the status quo on the grounds that the choice was difficult or very difficult or that they did not feel concerned, and respondents who were students, since they were not the ones making the decisions and their preferences were therefore biased. The final sample contained 1,088 rural and non-rural respondents (see Table 3.3 for a description of the sampling).

The questionnaire began by collecting the socio-demographic characteristics of the respondents. In the second section, it asked them a series of questions about their environmental practices and values, including in relation to the New Ecological Paradigm scale items. The NEP scale used in this study was drawn from another study that had developed a translation and validation of NEP items for Japanese people (Sasaki, 2016). The third section consisted of questions relating to the respondents' general knowledge of or familiarity with endangered species and their protection. This was followed by a series of questions relating to their knowledge of eels, the ecological situation of this species, and their own consumption of this species. These questions were in fact intended to stimulate respondents' thinking about eel

protection and prepare them for the choice experiment. The last section was devoted to the choice tasks, including the video treatment.

Table 3.3: survey objectives and data

	Objective	Done	After sorting
Region			
<i>Hokkaido</i>	150	160	133
<i>Chubu</i>	150	165	138
<i>Chugoku</i>	150	165	135
<i>Tohoku</i>	150	165	146
<i>Shikoku</i>	150	163	136
<i>Kanto</i>	150	158	138
<i>Kansai</i>	150	165	137
<i>Kyushu</i>	150	158	125
TOTAL	1,200	1,299	1,088
Town density level			
<i>Urban area: density>500 hab/km²</i>	600	826	688
<i>Rural area: density<500 hab/km² ^(a)</i>	600	473	400
TOTAL	1,200	1,299	1,088
Questionnaire version			
<i>Video with additional information– Block 1</i>	300	326	279
<i>Video with additional information - Block 2</i>	300	315	273
<i>Video without additional information - Block 1</i>	300	324	267
<i>Video without additional information - Block 2</i>	300	334	269
TOTAL	1,200	1,299	1,088

(a) https://www.oecd.org/cfe/regionaldevelopment/OECD_regional_typology_Nov2012.pdf

3.4. Sample characteristics

The basic socio-demographic characteristics of the respondents are shown in Table 3.4. The average age of our sample (1,088 individuals) was around 49 years old. Even if the objective was not to achieve a representative sample of the Japanese population, it is worth noting that

this average age is only one year above the national average. There were more men than women, which is not the case among the Japanese general population, and the level of education was slightly higher than the national level. The average household income was around 4.46 million JPY, which is significantly higher than the national average household income of 3.74 million JPY.

We measured respondents' level of environmental consciousness with two questions relating to the environmental actions that they favoured. The first category pertained to waste management (Supplementary material S2.2, Question 11.a): if respondents claimed to avoid buying single-use products or products with plastic packaging, they were considered to embrace pro-environmental behaviour. The second category related to their diet (Supplementary material S2.2, Question 11.b): if respondents claimed to be reducing their meat consumption, they were considered to embrace pro-environmental behaviour. On average, a third of our respondents seemed to have developed that type of behaviour (Table 3.4).

Respondents' level of environmental knowledge was also measured with two questions. They were first asked to give their opinion about what constitutes an endangered wild species by answering a multiple-choice question (Supplementary material S2.2, Question 13). If they gave one or more correct answer(s), they were considered as knowing what an endangered species is. Respondents were also asked to give their opinion about the status of the eel by answering a multiple-choice question (Supplementary material S2.2, Question 18). They were considered as knowing about the eel's status as an endangered species if they checked the corresponding answer. While the majority of the respondents seemed to understand quite clearly what constitutes an endangered species, this was not the case for the eel's status as an endangered species (Table 3.4).

The sample characteristics are summarized in the following table (Table 3.4).

Table 3.4: descriptive statistics and characteristics of the valid sample (N=1,088)

Variable	Description	Mean	S.D.	Min	Max	Average in Japan
Age	Age in years	48.85	13.35	18	82	47.9 ^(a)
Gender	= 1 if respondent is a man, = 0 if otherwise	0.56	0.50	0	1	0.49 ^(b)
Education	Categorical dummy for educational background (= 1 if Junior high school or Primary education, = 2 if High school or Secondary education, = 3 if Higher education)	2.61	0.53	1	3	2.28 ^(c)
Income	Categorical dummy for net household income (= 1 if < JPY2 million, ..., = 10 if > JPY10 million)	4.46	2.83	1	10	3.74 ^(d)
Pro-environmental behaviour	= 1 if yes, = 0 if no	0.33	0.47	0	1	-
Know what constitutes an endangered species	= 1 if yes, = 0 if no	0.66	0.47	0	1	-
Know that the eel has the status of an endangered species	= 1 if yes, = 0 if no	0.39	0.49	0	1	-

^(a) In 2021:

https://www.ipss.go.jp/syoushika/tohkei/Popular/P_Detail2023RE.asp?fname=T02-06.htm

^(b) In 2021:

https://www.ipss.go.jp/syoushika/tohkei/Popular/P_Detail2023RE.asp?fname=T01-03.htm

^(c) In 2020:

https://www.ipss.go.jp/syoushika/tohkei/Popular/P_Detail2023RE.asp?fname=T11-01.htm

^(d) National wage average in 2021: 311,800 yen per month, meaning 3,741,600 yen per year

<https://www.mhlw.go.jp/toukei/itiran/roudou/chingin/kouzou/z2022/dl/10.pdf>

4. Econometric analysis

4.1. Econometric modelling framework

It is now standard practice to describe the extent to which respondent i benefits from scenario j of choice set n using a random utility function comprised of the impact of the attribute levels and a stochastic component: $U_{ijn} = bX_{jn} + \varepsilon_{ijn}$, where X_{jn} corresponds to the vector for the level of the attributes, b represents the vector of parameters to be estimated, and ε_{ijn} is the stochastic element. More specifically, except in the case of the consumption limits, we chose to use an effect-coding technique to estimate the main impact of each non-monetary attribute level on respondents' choices (Holmes and Adamowicz, 2003). The lowest level of each of the non-monetary attributes (level of the status quo alternative) was the reference, so that the parameter for this latter level could be identified afterwards (Bennett and Adamowicz, 2001). The utility of the status quo scenario $U_{i,j=3;n=1,...,6}$ is only a function of the alternative specific constant because the value of the other attributes is set to zero. The utility functions underlying the choice process can be described as follows:

$$\begin{cases} U_i(j,n)_{j=1,2;n=1,...,6} = \beta_1 QUANTI \\ + \beta_2 SUB_CATFISH + \beta_3 SUB_SANMA + \beta_4 SUB_CONGEREEL \\ + \beta_5 NO_RESEARCH + \beta_6 AWAR_LAB + \beta_7 AWAR_CAMP \\ + \beta_8 ILLEGAL_LOW_INCR + \beta_9 ILLEGAL_HIGH_INCR \\ + \beta_{10} COST + \varepsilon_{ijn,j=1,2;n=1,...,6} \\ U_{i,j=3;n=1,...,6} = \alpha_3 ASC_STATUS_QUO + \varepsilon_{i3n,n=1,...,6} \end{cases} \quad (1)$$

When faced with the different alternatives $j; j = 1, 2, 3$ within each choice set $n, n = 1, 2, \dots, 6$, the respondent is assumed to select the alternative that gives him or her the most utility. The probability π that an individual i chooses alternative n from the choice set is then given by the following equation:

$$\pi_i(j,n) = \Pr \left\{ \beta X_{jn} + \varepsilon_{ijn} \geq \beta X_{kn} + \varepsilon_{ikn} ; j \neq k, \forall j = 1, 2, 3 \right\} \quad (2)$$

The conditional logit is the first candidate model to estimate the choice probabilities in Equation (2). Assuming that the error terms ε are independently and identically distributed (IID) and

follow the Gumbel distribution, the probability that alternative j would be chosen from choice set $n, n = 1, 2, \dots, 6$ is calculated with the following equation:

$$\pi_i(j, n) = \frac{\exp(\beta' X_{jn})}{\sum_{j=1,2,3} \exp(\beta' X_{jn})} \quad (3)$$

The probability of the observed sequence of choices for the $n, n = 1, 2, \dots, 6$ choice sets is quantified as follows:

$$P_{in} = \prod_{n=1}^6 \pi_i(j, n) \quad (4)$$

The conditional logit model assumes the independence of irrelevant alternatives (IIA), whereby the relative probabilities of two options being chosen are unaffected by the introduction or removal of other alternatives. The IIA property has to be confirmed by the Hausman and McFadden (1984) test. If IIA is violated, the choice alternatives are likely to be correlated and the conditional logit estimator will be biased. Furthermore, individual preferences are characterized by heterogeneity. If this heterogeneity is not taken into account, the modelling of preferences can produce results that are not consistent with reality. Understanding heterogeneity also provides insights on the distributional effects of conservation policy that are highly valuable from a policy perspective (Birol and Koundouri, 2008). Finally, heterogeneous preferences represent a significant issue for the evaluation of national conservation policies (Fujino et al., 2017). Yet the conditional logit model assumes homogeneous preferences among consumers, without testing the effects of interaction variables between some key individual characteristics and choice attributes (Adamowicz et al., 1997). This procedure thus remains limited, as it relies on an a priori selection and a restrictive number of individual characteristics and attributes (Boxall and Adamowicz, 2002).

The mixed logit model relaxes the IIA assumption and accounts for unobserved and observed heterogeneity in preferences (Hensher et al., 2015). However, the alternative, namely using models with all or some of the effects of scenarios' attributes being random parameters, presents complex identification and interpretation problems for the researcher (Schmidt et al., 2019). The latent class logit (LCL) model (Hensher and Greene, 2002) allows for individuals to be grouped into relatively homogeneous classes (i.e. individuals who belong to the same class exhibit identical preferences), and for explaining the choice behaviour of the members of those classes. The results of the latent class model specification highlight differentiated behaviour

across the preference groups. Moreover, evaluation targeting specific groups is key to formulating public policy prescriptions.

The LCL model allows for a joint estimation of the latent construction of preference heterogeneity based on individual characteristics and policy scenario choices relating to these scenarios' attributes. If we assume the existence of S classes of preferences within our population, according to individual characteristic Z_i , the membership probability function for individual i also follows the multinomial logit model: $\pi_i(s) = \frac{\exp(\alpha\lambda_s Z_i)}{\sum_{s=1}^S \exp(\alpha\lambda_s Z_i)}$. The

probability that a randomly chosen individual i will join class s and choose the alternative j in choice set n is therefore given by the following equation:

$$\pi_i(s, j, n) = \sum_{s=1}^S \left[\frac{\exp(\alpha\lambda_s Z_i)}{\sum_{s=1}^S \exp(\alpha\lambda_s Z_i)} \right] \left[\frac{\exp(\mu_s \beta_{sj} X_{jn})}{\sum_{k=1,2,3} \exp(\mu_s \beta_{sk} X_{kn})} \right] \quad (5)$$

This model allows us to explain choice behaviour related to scenario attributes and individual respondents' characteristics simultaneously. The λ_s and β_s parameter vectors are estimated using the maximum likelihood method. For the λ_s vector, the parameters for one of the classes must be normalized to 1 to allow for the identification of class membership parameters for the other classes.

Finally, to determine whether significant differences exist between the classes obtained, we can use the posterior probabilities that an individual respondent is in particular classes, since his or her choice sequence $\pi_i(s, j, n); j = 1, 2, 3; n = 1, 2, \dots, 6$ opens up the possibility, at sample level, to reconstruct (calculate) the distribution across the different classes of individual characteristics not included in the model specification during estimation (Amaris et al., 2021).

4.2. Sources of heterogeneity

To examine the heterogeneity and the existence of different classes of preferences for different policy scenarios, we considered several individual characteristics. The abundant empirical literature on pro-environmental behaviour has shown that sociodemographic characteristics condition the likelihood of engaging in pro-environmental actions. Three main variables are often closely studied in the field of environmental policy valuation: respondents' education

level, their age and income – all as proxies of personal capabilities for understanding scientific issues –, and the resources required (time, financial budget) for the environmental cause.

In addition to socio-demographic characteristics, individuals' knowledge of the environment has been associated with individual choice behaviour. In examining environmental knowledge, we specifically focused on knowledge of threatened species and distinguished between knowledge of common threatened species, on the one hand, and awareness of the eel's status as a threatened species on the other. We posited that people with more accurate knowledge of threatened species were more likely to favour certain policy instruments. Likewise, we expected that those with specialized knowledge about the ecological status of eels would prefer suitable policy instruments. These expectations are in line with some of the research on climate change mitigation, which demonstrates that awareness of environmental threats is a driver of pro-environmental behaviour as a risk prevention behaviour (Bockarjova and Steg, 2014; Whitmarsh et al., 2021).

We also specifically explored the influence of consumers' environmental concerns and values. In this study, we focused on the active dimension of environmental concern, that is, pro-environmental practices. Past pro-environmental behaviours can lead individuals to be more concerned about the environment (Maki et al., 2019), so as to maintain a certain coherence in their actions (Van der Werff et al., 2014), or to maintain a good self-image (Czajkowski et al., 2017). The result is a positive spill-over effect between pro-environmental behaviours. We chose two past practices: sorting plastic waste and limiting the use of plastic packaging; and reducing meat consumption. Among the multitude of actions that can limit human impact on the environment, some authors consider only those types of action that carry a cost for the individuals implementing them (Diekmann and Preisendörfer, 2003). Recycling plastics or reduction of meat consumption are therefore debated as pro-environmental actions in the context of developed countries (Andersson and von Borgstede, 2010; Berthold et al., 2023). However, these indicators are quite specific in the case of Japan, knowing that the use of plastic is an ongoing issue (Ohtomo and Ohnuma, 2014). Even though meat consumption does not have such a high impact on households' carbon footprint in Japan, it seems that Japanese people's desire to reduce their meat consumption could be linked to their environmental consciousness (Sasaki et al., 2022).

Finally, there is evidence that people living in rural areas have different preferences from those in urban areas when it comes to species conservation. In many cases, conservation and

biodiversity protection can have a more direct impact on people living in rural areas, where the habitats of many species to be protected are located. These rural households are less inclined to support conservation actions that could have a negative impact on them (Bartczack and Meyheroff, 2013). In this study, we also expected a significant difference in consumer preferences between rural and urban areas. We posited that consumers living in rural areas were closer to eel fishing activities, and therefore likely to be more sensitive to the preservation of eel production activities as a local heritage (Sakurai and Shibusawa, 2021).

It is quite conceivable that individuals' general beliefs and value orientations might also influence preferences. The NEP scale has become the most widely used tool for measuring environmental awareness in survey-based empirical studies, as well as a standardized measure of environmentalism (or pro-environmental orientation) for cross-cultural comparison purposes. Conceptually, this scale was built on a set of general (or primitive) beliefs that should fit into a causal model between values and specific beliefs about environmental problems (Stern, 2000). The NEP scale is composed of 15 statements assessed on a five-point Likert scale, ranging from "strongly agree" to "strongly disagree" and grouped into five core facets: "limits of economic growth"; "anti-anthropocentrism"; "fragility of the natural balance"; "rejection of human exceptionalism"; and "eco-crisis". Individual respondents' NEP scores are therefore also latent constructs. Integrating these latent variables (15 in total) into the modelling of preferences necessitates specifying a hybrid mixed logit model to achieve convergence and unbiased estimation (Aansen et al., 2023). In this study, we kept the specification of a latent class model, but used posterior probabilities to conduct an analysis of the 15 NEP scale scores across classes.

4.3. Testing the impact on preferences of information about the eel trade

We must first investigate whether the choice patterns of the treated group (sub-sample of respondents receiving additional information about the eel trade) were different from those of the control group (sub-sample of respondents responding to the neutral protocol). For each sub-sample, the proportions of choices made for each scenario, including the status quo scenario, are shown in the following table (Table 3.5).

Table 3.5: proportions of choices made for each scenario (N=19,584) for the group that received additional information about eel trade (long-version video) and the one that did not (short-version video)

	Short-version video	Long-version video	Total
Alternative 1 was chosen	5.7%	6.0 %	11.7 %
Alternative 2 was chosen	6.1%	6.3 %	12.4 %
Alternative 3 was chosen (status quo)	4.6%	4.6 %	9.2 %
No alternative was chosen	32.8%	33.8 %	66.7 %
Total	49.3%	50.7 %	100 %

The distribution of the choices is relatively similar across the two groups. The Pearson chi-square test result is equal to 0.4965 with a p-value of 0.992, which confirms that the choice distribution is not different in the two groups.

We therefore apply a non-parametric approach to choices across the alternatives in each choice set for the control group and the treated group, to test the null hypothesis that the distribution of choices across alternatives in each choice set is the same in both the control and the treated group (Broberg et al., 2021). The Pearson chi-square test results for this hypothesis are presented in Table 3.6.

Table 3.6: Pearson chi-square testing the null hypothesis that the distribution of choices across alternatives in each choice set is the same for both the control and the treated group

Choice set number	Pearson chi2(3)	p-value
1	0.0711	0.995
2	0.2642	0.967
3	0.0169	0.999
4	0.2486	0.969
5	1.8460	0.605
6	0.6591	0.883

According to the results (Table 3.6), the difference between the two groups is not significant and the null hypothesis can therefore be validated.

The provision of additional information on the eel trade was supposed to induce a change in individual choices of policy scenarios, by causing a shift in the trade-offs that individuals made between different categories of instruments. We examine this hypothesis with the estimation of a conditional logit model for all observations by merging the datasets from both sub-samples. Alongside the attribute variables used to explain choice data, we introduce their interaction effects with an indicator variable for the choice data obtained from the treated group, with the dummy variable “VIDEO” taking the value of 1 when the choice was made after the long version of the video and 0 otherwise. This procedure enables us to test whether the provision of information did indeed lead respondents to reveal different preferences, which would be reflected by a significant change in the mean values of the estimated coefficients of all the attributes, including the alternative specific constant for the status quo alternative. Cluster robust variance estimators for within-group error correlation are implemented for this procedure. The estimation of this conditional logit model on the whole sample is provided in the following table (Table 3.7).

The results of Table 3.7 show that only the interaction of the attribute variable “no research development” with the “VIDEO” variable has a positive and significant impact at a p-value of 10%. This means that the treated group presents a lower valuation of this attribute. Furthermore, the value of the associated Wald test statistic (Chi^2 (11)), used to determine whether the coefficients of all interaction variables are jointly insignificant, is 7.23, with a probability of 0.78. The information collected did not reveal sufficiently significant changes in the appraisal of the same scenarios to point to contrasting preferences. These results suggest that in-depth knowledge of eel trade channels (legal and illegal) cannot influence consumer choices and their preference for one policy instrument over another.

Table 3.7: Conditional (fixed-effects) logistic regression with the effects of interaction with the “VIDEO” variable

	Coefficient	Standard error
Status quo	-0.18*	0.1
Consumption quantity	0.15*	0.08
Substitution with catfish	-0.09	0.07
Substitution with sanma	0.005	0.08
Substitution with conger eel	0.27***	0.07
No research development	-0.32***	0.05
Increase awareness with a label	0.15***	0.06
Increase awareness with a campaign	0.22***	0.06
Low increase in control of illegal trade	0.08	0.06
High increase in control of illegal trade	0.09*	0.05
Increase in the price of kabayaki	-0.001**	0.0006
Status quo * VIDEO	-0.08	0.14
Consumption quantity * VIDEO	-0.13	0.11
Substitution with catfish * VIDEO	0.01	0.10
Substitution with sanma * VIDEO	-0.04	0.12
Substitution with conger eel * VIDEO	-0.03	0.09
No research development * VIDEO	0.11*	0.06
Increase awareness with a label * VIDEO	-0.05	0.08
Increase awareness with a campaign * VIDEO	-0.08	0.08
Low increase in control of illegal trade * VIDEO	0.03	0.08
High increase of illegal trade control * VIDEO	-0.02	0.07
Increase in the price of kabayaki * VIDEO	-0.00007	0.0009
AIC	14,087.78	
Number of respondents	1,088	
Number of observations	19,584	

Note: ***significant at 1%; **significant at 5%; *significant at 10%.

From a statistical perspective, this means that, overall, the individuals belonging to the two sub-samples made their choices in a similar way, and that it is relevant to carry out the remainder of the econometric analysis with the two sub-samples merged. We provide the results of the estimation of the conditional logit model for the full sample in the following table (Table 3.8).

Table 3.8: Conditional (fixed-effects) logistic regression

	Coefficient	Standard error
Status quo	-0.23***	0.07
Consumption quantity	0.08	0.05
Substitution with catfish	-0.09	0.07
Substitution with sanma	-0.02	0.06
Substitution with conger eel	0.26***	0.05
No research development	-0.27***	0.03
Increase awareness with a label	0.13***	0.04
Increase awareness with a campaign	0.17***	0.04
Low increase in control of illegal trade	0.09**	0.04
High increase in control of illegal trade	0.08**	0.03
Increase in the price of kabayaki	-0.001***	0.0004
AIC	14,073.01	
Number of respondents	1,088	
Number of observations	19,584	

Note: ***significant at 1%; **significant at 5%; *significant at 10%.

On average, sampled respondents supported the implementation of policy-mix schemes aimed at the conservation of eel species. More specifically, the ASC (Alternative Specific Constant) for the status quo alternative is negative and significant. Results also show that on average, individuals did not reveal any preference for consumption limits. The coefficient of the attribute is positive but non-significant. Regarding the consumption of substitute species, the results indicate that, on average, the public has a strong preference for conger eel as a substitute for eel and is willing to pay a higher price for this species to promote eel conservation. All other things being equal, a scenario that does not involve the development of research into artificial eel reproduction is associated with a lower utility than one that does. The coefficient of the variable “No Research” is significant and negative. On average, respondents ascribe positive value to information-based instruments and to the fight against illegal trade. The coefficient for the cost

attribute is significant and has the expected sign. However, the IIA assumption is significantly invalidated when any of the three choice alternatives are omitted. As a result, a latent class model was used to model the heterogeneity of preferences and to relax the conditional logit model's IIA assumption.

4.4. Latent class logit modelling

The first step of the econometric procedure for the latent class approach to choice probability presented in Equation (4) corresponds to the estimation of a class membership function. In order to determine the optimal number of classes, we tested 2-, 3- and 4-class solutions. Table 3.9 summarizes the aggregate statistics for these models.

Table 3.9: Akaike's information criterion (AIC) and the Bayesian information criterion (BIC) with 2, 3 and 4 latent classes (19,584 observations)

Number of latent classes	AIC	BIC
2	13,050.64	13,231.93
3	12,840.88	13,116.76
4*	3,371.519	3,458.226

* Convergence not achieved

We used the two criteria most used (Kamakura and Wedel, 2004) to determine the number of classes: the minimum Akaike Information Criterion (AIC) and the minimum Bayesian Information Criterion (BIC). These statistics reveal improvement in the model fit as classes are added to the procedure, particularly with the 3-class model. However, the 4-class model does not converge, which points to the 3-class being the optimal solution. We thus account for the heterogeneity of preferences within a three-latent-class model specification. The results in Table 3.10 show the parameter estimates for attributes within each class, as well as the effect of a specific individual characteristic on the class allocation model.

Table 3.10: Latent class model estimates with three latent classes

(a) Class preferences

	Class 1		Class 2		Class 3	
	Coefficient	Standard error	Coefficient	Standard error	Coefficient	Standard error
Status quo	-0.57***	0.14	0.61***	0.18	-2.07***	0.33
Consumption quantity	-0.18	0.10	0.07	0.16	0.53***	0.17
Substitution with catfish	0.63***	0.12	-0.58***	0.13	-0.98***	0.18
Substitution with sanma	1.37***	0.17	-0.98***	0.15	-2.18***	0.38
Substitution with conger eel	0.55***	0.1	-0.31**	0.13	0.29**	0.14
No research development	0.05	0.06	-0.34***	0.1	-0.91***	0.17
Increase awareness with a label	0.3***	0.08	-0.01	0.13	-0.001	0.13
Increase awareness with a campaign	0.23***	0.08	0.11	0.13	0.2	0.17
Low increase in control of illegal trade control	-0.13	0.09	0.18	0.11	0.26	0.17
High increase in control of illegal trade control	0.03	0.07	0.15	0.12	0.12	0.12
Increase in the price of kabayaki	-0.003***	0.0009	-0.004***	0.001	0.004***	0.002
AIC	12,840.88					
Number of respondents	1,088					
Number of observations	19,584					

Note: ***significant at 1%; **significant at 5%; *significant at 10%.

(b) Class allocation

		Coefficient	Standard error
Share1	< 40 years old	0.46*	0.27
	40-60 years old	0.26	0.23
	Income < 4,000,000 yen	0.37*	0.21
	Income ≥ 8,000,000 yen	0.35	0.28
	Pro-environmental behaviours =1	-0.19	0.2
	Live in rural area	-0.004	0.2
	Know what constitutes an endangered species	-0.33*	0.2
	Know that the eel has the status of an endangered species	-0.5**	0.2
	_cons	0.37	0.33
Share2	< 40 years old	0.46*	0.27
	[40-60[years old	0.21	0.23
	Income < 4,000,000 yen	0.2	0.21
	Income ≥ 8,000,000 yen	0.46*	0.27
	Pro-environmental behaviours =1	-0.6***	0.2
	Live in a rural area	0.48**	0.19
	Know what constitutes an endangered species	0.37*	0.21
	Know that the eel has the status of an endangered species	-0.37*	0.19
	_cons	-0.41	0.32

Notes:

- Share1, Share2 and Share3 are conformable column vectors of membership model coefficients for classes 1, 2 and 3, with Share3 normalized to 0 for identification (<https://doi.org/10.1177/1536867X20931003>)
- The education level was tested but the results were not significant. We selected the model for which the characteristics were significant.
- ***significant at 1%; **significant at 5%; *significant at 10%.

First, we look at the parameters that vary across the three classes, and provide a “value orientation” interpretation of the respondents’ policy preferences (Table 3.10 (a)).

Class 1 – “*Liberal conservationism*”: this class corresponds to individuals who will suffer a substantial loss of utility with the maintenance of the status quo (without additional public intervention). However, consumption limits have no effect on utility for this group. Research on artificial eel reproduction also has no influence on the acceptability of a policy scenario. These respondents favour a conservation strategy based on substitute species. All fish species substitutes show a substantially higher utility than eel species. This is in keeping with the previous result. Moreover, conger eel as a substitute species has a greater influence on utility in this class than in Class 3. Finally, this class corresponds to individuals with a very positive perception of awareness instruments as a complement for substitute species. The two attributes that correspond to a voluntary approach to conservation policy (focusing on public information and awareness) are only significant in this class. Ramping up the fight against illegal trade is not perceived to increase utility in this group – nor is it in the other groups. Regarding the impact of a price instrument on utility, increasing the price of *kabayaki* negatively influences the acceptability of a policy scenario for this class.

Class 2 – “*Environmental scepticism*”: this class corresponds to individuals who have a positive perception of the current situation. The ASC of the status quo alternative is positive and significant. Consumption limits are not an attribute that influences the utility of a policy scenario in this class. These respondents are individuals who have a strong aversion to eel substitute species. All estimates for the three substitutes are negative and significant. This pattern clearly signals a very strong preference for eel consumption. The individuals have a negative view of a public intervention scenario that would halt research into the artificial eel reproduction. Awareness instruments have no influence on utility in this class. The negative impact of the increased price of *kabayaki* on utility is much greater than for Class 1.

Class 3 – “*Responsible consumerism*”: in this class, without a policy intervention, individuals will suffer a higher loss of utility than in Class 1. Moreover, compared to Class 1, the individuals’ utility increases when a more restrictive consumption limit is imposed. Individuals report a loss of utility if part of their eel consumption is replaced with catfish or sanma. On the other hand, they report a positive utility if eel is replaced by conger eel. However, in this class, the utility gain with this substitute is much lower than for Class 1. Individuals have a decrease in utility when research on artificial eel reproduction is stopped. The estimates show that this

loss is much greater for this class than for Class 2. Finally, in this class, individuals are insensitive to awareness tool but derive positive utility from significant increases in the price of *kabayaki*.

The second part of the model estimates provided in Table 3.10 (b) relates to the class allocation model. This component of the latent class model explains which respondents are more likely to fall into specific classes. At sample level, there is a 40% probability of falling in Class 1, 31% in Class 2, and 29% in Class 3. These sample-level class allocation probabilities are largely informed by the respondents' individual characteristics and random terms, as the constants of regression are not significant.

Being under the age of 40 increases the likelihood of belonging to the “Liberal conservationism” group (Class 1) or the “Environmental scepticism” class (Class 2). Individuals with a low level of income are more likely to belong to the conservationist class, while individuals with the highest level of income are more likely to belong to the sceptic class. Those who already engage in pro-environmental behaviour have a lower probability of falling in Class 2. This finding is entirely in line with expectations. It is worth noting that knowledge of what constitutes an endangered species reduces the likelihood of belonging to the conservationist class (Class 1), but increases the likelihood of belonging to the sceptic class (Class 2). Furthermore, being aware that eel is an endangered species reduces the likelihood of belonging to Classes 1 and 2. Finally, those living in rural areas have a higher likelihood of falling in Class 2 than those living in urban areas.

Class membership and endorsement of NEP items

The alpha tests indicate that the NEP scale is working for the Japanese population (Supplementary material S2.4 (b)). The Cronbach's alpha coefficient for each question and the full scale were up to 0.8, which is considered a very good internal consistency (Dunlap et al., 2000; Noblet et al., 2013). The NEP scores are quite high, particularly on the odd-numbered questions (pro-NEP questions). With the exception of the first question, the average score on these questions is higher than 5 (Supplementary material S2.4 (a)). The respondents were therefore mainly pro-NEP. The application of an exploratory factor analysis extracted two factors (Supplementary material S2.4 (c)). The first factor analysis was formed by the odd-numbered items (pro-NEP) and represents respondents who were assertive in their choices and gave high scores to pro-NEP items, while even-numbered items (anti-NEP) were found to load the second factor and represents respondents who gave high scores to anti-NEP items but less

assertively. The fact that the answer “I don’t know” was chosen more frequently for even-numbered questions (Supplementary material S2.4 (a)) supports the hypothesis that eel consumers in Japan express themselves more easily in relation to pro-NEP (odd-numbered) questions, or at least that respondents who express clear-cut opinions about these questions outnumber those who express themselves easily on anti-NEP (even-numbered) questions. Pro-NEP Japanese are more numerous but find it harder to express themselves on anti-NEP questions.

Based on the estimated individual-specific posterior class membership probabilities from the three-classes LCL model, we calculated the proportion distribution of each NEP item and average scores for each class (Supplementary material S2.5). The highest average scores on odd-numbered items are in Class 3 (up to 5.6). They are also significantly higher than the mean scores. The proportions of high scores (5, 6 and 7) are also highest in Class 3 across all items (odd- and even-numbered), where the proportions of pro-NEP individuals are higher than average. This is also the case for Class 2. The proportions of low scores (1, 2 and 3) are higher than average in Class 1, but also surprisingly so in Class 3. Anti-NEP individuals are therefore predominantly found in Classes 1 and 3. The pro-NEP individuals in Class 3 are characterized by their belief in the existence of environmental limits to the growth of human activity (“limits of economic growth”) and in the fact that humanity is heading towards serious disruptions to the functioning of its natural environment (“eco-crisis”), as well as their belief in the importance of respecting natural balances (“fragility of the natural balance”) and that modern industrial society does not allow humans to break free from the laws of nature (“rejection of human exceptionalism”). Anti-NEP individuals in this same class oppose this, seeming convinced less of the importance of respecting natural balances and more of human exceptionalism. The pro-NEP individuals in Class 2 are characterized by their belief in the importance of respecting natural balances. In Class 1, the least pro-NEP of the three classes, pro-NEP individuals are less convinced of the importance of respecting natural equilibria and of the fact that humanity is heading towards serious disruptions to the functioning of its natural environment, while anti-NEP individuals are characterized by their anthropocentrism.

Several authors advise caution in interpreting the NEP results (Barradas and Ghilardi-Lopes, 2020; Rosa et al., 2021). There is evidence of acquiescence bias in the New Ecological Paradigm (NEP) when applied to Japanese individuals, particularly with a tendency towards “centralization” (Sasaki, 2016). It can be attributed to cultural differences between Western and Eastern societies. Eastern respondents may have difficulty expressing strong opinions. While

this bias is less pronounced in Class 3, there are still significant differences between the highest proportions of pro-NEP responses to odd-numbered questions (ranging from 65% to 82%) and those to even-numbered questions (ranging from 22% to 43%). Thus, all classes are affected by this bias.

5. Discussion and policy implications

This paper empirically examines individual decisions between two hypothetical policy instrument mixes and the status quo situation for the conservation of eel species in Japan. The “policy mixes” scenarios were composed of five policy attributes that have proved to be important in the conservation literature and the current situation corresponds to the “no additional public intervention”. Our econometric analysis with latent class logit model reveals overall strong preference to move away from the status-quo (about 69% of respondent). In this respect, our estimation results suggest that not only introduction and promotion of substitutes should be applied, but also consumer-targeted interventions such as awareness campaigns and fish product labelling, which is in line with previous studies applying DCE for Japan (Hori et al., 2020; Wakamatsu and Managi, 2022) and other countries (Menozzi et al., 2020; Solgaard et al., 2023). In addition, our estimation results show that one third of the sampled citizens clearly and significantly prefer quantitative reduction targets of eel products’ consumption and public interventions that lead to higher market prices, which contrasts to previous findings for other contexts (i.e. Chen and Sas-Rolfes, 2021). However, our estimation results also reveal that a significant proportion of respondents (also one third of the sample) expresses a refusal to recognize eel consumption as an environmental problem to be resolved with additional public intervention, which suggests that the consumption of eel products continues to be partially motivated by socio-cultural factors and traditions (Thomas-Walters et al., 2020).

There is no preference observed for intensifying control to prevent illegal trade. The status quo seems sufficient for Japanese citizens, since there is already some level of control in place, including the enforcement of regulatory measures. Indeed, IUU glass eel fisheries in Japan’s waters would be drastically reduced due to the amendment of the Fisheries Act and the implementation of the Proper Distribution Act. However, management of glass eel imports into Japan will not be substantially improved because the Fisheries Act is only effective for domestic glass eel fisheries, and glass eels imported from other countries is not subject to the Proper Distribution Act so far. Documents regarding the Proper Distribution Act describe glass eel as

‘eels smaller than 13 cm’ and do not specify the species; therefore, listing glass eels in Class II would be beneficial not only for the Japanese eel but also for other Anguillid eel species. To sum up, improvement of glass eel imports can help in the conservation and sustainable use of Anguillid eels, and, overall, the respondents in this study were indifferent between introducing more stringent control on glass eel imports or maintaining the *status quo*. To the best of our knowledge, there are no previous studies that have examined this topic in the context of endangered or threatened fish species. Our finding suggests that for instance there is limited public support of the Japanese government in listing glass eels in Class II of the Proper Distribution Act, which aims to combat the import of aquatic animals and plants that are fished or traded illegally.

In terms of preference heterogeneity, three different classes were identified. A first class corresponds to Japanese individuals under the age of 40 living in urban areas, with an average to low income. This type of Japanese eel consumer is the most common within the population, and prefers to implement market-oriented instruments such as substituting eel consumption with that of other species like conger eel, sanma or catfish, or initiating large-scale information campaigns. In spite of this, these liberal conservationists, who wish to see eel consumption regulated with gentle methods, seem to have lower levels of knowledge and environmental sensitivity than the rest of the population. Some of these individuals are even characterized by anthropocentrism. The second class also includes Japanese individuals under the age of 40, but this time living in rural areas and with very high incomes. This type of Japanese eel consumer is rather conservative and prefers the status quo, advocating the development of research on artificial eel reproduction. These individuals, although sceptical of change, have higher levels of knowledge and environmental sensitivity than those in Class 1. They are particularly characterized by their belief in the importance of respecting natural balances. The last class corresponds to Japanese individuals over 60 years of age living in urban areas, with relatively high salaries. This type of Japanese eel consumer prefers to implement demand-regulation instruments through price increases or a reduction in quantities consumed. These responsible consumers have an even higher level of knowledge and environmental sensitivity. However, this class also includes individuals who claim to have a lower sensitivity to environmental issues, with a belief that modern industrial society allows humans to break free from the laws of nature, and who therefore do not share the viewpoint of Class 2 individuals regarding the importance of respecting natural balances.

Our empirical analysis thus reveals that for instance, individual knowledge and environmental concerns plays an ambiguous role for the preferences for ambitious policy mixes (i.e. including coercive policy instrument). Our results also reveal that the most pro-environmental respondents in their policy mixes choice are positive about research on artificial reproduction. These findings may support the further implementation of management measures in Japan. However, careful consideration is required to develop actual measures because they might not represent the views of all Japanese citizens due to methodological limitations, and groups with different opinions were found among the respondents. Despite such limitations, our results provide some insights that would be useful to consider Anguillid eel management in Japan, and the high relevance of engaging into controversial political discussion about eel species conservation in Japan, and globally.

It is critical that individuals both consume pro-environmentally and support conservation policy, since combining these actions can lead to sustainable fisheries and more effective conservation of a threatened species. In this study, we found evidence that people who behave pro-environmentally would be more supportive of the introduction of more restrictive policies. In addition, people are more likely to support policies and behave pro-environmentally when their intrinsic pro-environmental motivation and concern is strong. Our study also found that older people generally have more environmentally positive attitudes than younger people, which is in contrast to previous studies (i.e. Boeve-de Pauw et al., 2010; Disprose et al., 2019). Based on these results, policymakers might increase consumers' engagement by making it easier for people to improve their intrinsic pro-environmental motivations and values (Schultz and Zelezny, 1999). Previous studies claim that environmental values can potentially be formed and changed through education (Meyer, 2015), highlighting the importance of developing and improving environmental education programmes to enhance environmental citizenship in young citizens.

THIRD CHAPTER

French connections: a socio-ecological system modelling approach for the restocking of European eel

A version of this chapter is being prepared for submission to Marine Policy¹

« Tolérante et pragmatique, la pensée systémique s'ouvre à l'analogie, à la métaphore, au modèle. Jadis exclus de la "méthode scientifique", les voici aujourd'hui réhabilités. Pour l'approche systémique, tout ce qui décroïssonne la connaissance et débloquent l'imagination est bienvenu : elle se veut ouverte, à l'image des systèmes qu'elle étudie. »

Joël de Rosnay, Le macroscop, 1975

¹Authors: Froehlicher H., Rambonilaza T., Daverat F., Pereau JC.

French connections: a socio-ecological system modelling approach for the restocking of the European eel

Abstract

In this survey, we aim at understanding the effectiveness of European eel restocking as a socio-ecological system (SES) involving interactions between ecological, socio-economic and institutional factors. We applied this perspective to explore issues concerning the management of the European glass eel fishery within the Loire Basin Management Unit in France. This management basin is of particular interest as France is the only country that has a system of fishing quotas for glass eel to prioritise restocking projects, such that in theory only unused quotas can supply the domestic consumption market. More specifically, we characterised this management territory as a SES using a parsimonious set of variables. We reconstructed the interactions between these variables based on the existing literature and results of a survey among professional fishers of the study case. We use a qualitative loop analysis that exploits the structure of these interactions, to identify the pathways responsible for the propagation of impacts and feedbacks that modulate the effects of different management measures (that would complement eels restocking) on fishing effort, stock level, and fishers' income, then advancing an ecosystem-based management of glass eels' fishery. We have tested the effects of lower allowable quota for consumption market, fishing effort regulation or shift to complementary/accompanying species, and price-based instrument (subsidised price for the restocking sector or additional tax for the consumption sector). According to our results, scenarios focusing on regulating the fishing effort would be the most ecologically and socio-economically viable.

1. Introduction

Scientific consensus has established that the planet is experiencing the sixth mass extinction (Cowie et al., 2022). Among vertebrates, freshwater fish experienced the highest rate of extinction in the world in the 20th century (Guy et al., 2021). Migratory species of freshwater fish, which need to migrate between environments (rivers and sea) or within river systems to complete their life cycles, are particularly threatened (Waldmann and Quinn, 2022). At local level, extinction or decline in the abundance of freshwater fish is probably the result of the cumulative effect of over-exploitation and of multiple human pressures on their aquatic environment (Mota et al., 2014). Of all the migratory fish species found in Europe, the European eel (*Anguilla anguilla*) is listed on the IUCN Red List of Threatened Species as Critically Endangered. This is due to a 90-95% decline in the recruitment of the species in the last 45 years across a large portion of its distribution range (Jacoby and Gollock, 2014). The largest declines were observed between 1980 and 2010, but recruitment remained at low levels after this period (ICES, 2022). The decline in the abundance of European eel stock is believed to result from the cumulative effect of multiple human pressures on their aquatic environment, including habitat loss and dams that reduce the accessibility of growth habitats (Besson et al., 2016), pathogens and pollution (Feunteun, 2002; Sjöberg et al., 2009), and overfishing (Feunteun, 2002; Jacoby et al., 2015).

European Council Regulation No. 1100/2007 published in September 2007 requires that all Member States in which there are European eel natural habitats establish eel management plans. The objective must be to allow the escapement of at least 40% of the supposed pristine stock of silver eel biomass to reach the sea. To this end, and in addition to habitat restoration and barrier removal programs, restocking has been promoted to improve local eel stocks, in a context where natural immigration of recruits has dropped by 90% of the 1970s reference values (Ovidio et al., 2015; Simon et al., 2013). However, as aquaculture artificial reproduction of eel is not yet possible, the only source of juveniles for restocking comes from glass eel fishing (Pedersen and Rasmussen, 2016). Restocking is therefore achieved through the translocation of mainly glass eels or elvers, sometimes yellow eels, from their natural habitat to different sites such as lakes or rivers. In this context, the regulation of glass eel fisheries is key to creating incentives for sustainable fisheries (Gutiérrez et al., 2011; Melnychuk et al., 2021) and even for conservation. EU regulation sets a target of 60% of catches to be used for restocking by Member States that have chosen to introduce this measure in their management plan.

Like other EU Member States (MS), France has implemented restocking measures since 2011. It is the country with the highest eel landing records for both stages: juveniles (glass eels) and adults (ICES, 2019). Adult stages are sold on the food market while glass eels are used for restocking and consumption purposes. French glass eels are used to restock French rivers but are also sold to other MS that have chosen to set up restocking schemes, mainly Germany, the Netherlands and Denmark (FranceAgriMer, 2022). Compared to restocking, glass eel fishing for consumption is a highly lucrative niche for professional fisheries. In 2018, French fishermen were selling a kilogram of glass eel for approximately €250 for restocking and €380 for consumption (Feunteun and Prouzet, 2020). This price difference presents real challenges for the conservation of European eels. After the 2010 CITES (Convention on International Trade in Endangered Species of Wild Fauna and Flora) ban on the export of European eel outside the EU, illegal trade emerged and increased the complexity of conservation challenges. A kilogram of glass eel can be sold for between €800 and €3,000, and the net margin for “operators” is over €1,000 (FranceAgriMer, 2014). Under these conditions, even honest fishers are unable to resist the attraction of illegal harvests for export to Asia (Kenzo et al., 2019).

To maximize the chances of success of European eel conservation, restocking is now part of an overall approach to European eel conservation policy, which includes the regulation of fisheries and requires the support of local communities (Nzau-Matondo et al., 2019, Simon, 2023). Ultimately, eel restocking shifts the conservation of an endangered species to the governance of an exploited natural resource. As such, the restocking of European eels can be seen as a social-ecological system with numerous interactions between ecological, economic, and institutional components and outcomes (Ostrom, 2009; Berkers, 2011; Schlüter et al., 2012; McGinnis and Ostrom, 2014). Fishery systems, whether in their natural or social dimensions, demonstrate a remarkable ability to self-organize in response to a wide array of stimuli (Mahon et al., 2008). These stimuli include internal feedback loops that operate within the system, such as those influenced by resources and market dynamics. Furthermore, fishery systems exhibit adaptability to external factors and are responsive to the influence of the governing system that oversees them. Therefore, the socio-ecological system (SES) framework has been broadly applied to fishery systems and the associated management issues (Naranjo-Madrigal et al., 2015; Ommer et al., 2012; Kittinger et al., 2013; Lade et al., 2015; Martone et al., 2017; Refulio-Coronado et al., 2021).

We have developed the SES in which restocking takes place, based on the activities of one of the largest glass eel fishing communities in the Loire estuary in France. However, integrating

information on the different dimensions of eel restocking as a SES into a modelling approach can prove difficult. This is due to the necessity of interdisciplinary knowledge integration, on the one hand, and the heterogeneity or scarcity of available data and information, on the other. Loop analysis only requires the sign (positive or negative) of the relationship between the variables to be specified. This simplicity overcomes the problem of a lack of quantitative data and converts the complex processes in which variables take part within a specific dimension, into tractable data (Niquil et al., 2021). Loop analysis is appropriate here to qualitatively reconstruct causal linkages and predict the expected impacts of the driver of change within each scenario. Such qualitative modelling has been applied in the context of sustainable fisheries and aquaculture, among other fields (Dambacher et al., 2015; Martone et al. 2017, Scotti et al., 2021). More specifically, loop analysis is used to study the dynamics of complex fishery systems where the signs of interactions between established variables are known but other aspects of their linkages are uncertain, including the strength of the interactions and their functional forms and parameters; in other words, whether one component of the system (e.g. species, actors or user groups) has a positive or negative effect or no effect on another component with which it interacts.

This research endeavors to use loop analysis (Justus, 2006) to identify the pathways responsible for the propagation of impacts and feedbacks that modulate the effects of different management scenarios that would complement eel restocking. We have been testing five different scenarios including three management actions acting directly on fisheries: reducing the consumption quota; regulating fishing effort and ultimately encouraging the fishing of a complementary/accompanying species. As the determination of eel prices is a demand-driven process, we have been testing two economic tools: the introduction of direct subsidies to fishermen, and the introduction of cross-subsidies through a levy on fish merchants, to fund restocking. This contribution is valuable because existing research into the management of this fishery (Hanel et al., 2019) excludes socio-economic effects.

A limited number of applications to investigate complex SES in the context of fisheries have used loop analysis (Carey et al., 2014; Dambacher et al., 2015; Espinoza-Tenorio et al., 2013; Martone et al., 2017). A major contribution of this paper is that ecologically and socio-economically viable scenarios, all of which hinge on the implementation of measures aimed at alleviating fishing pressure on elver resources.

The remainder of the paper is structured as follows. Section 2 clarify the link between the action of restocking and ecosystem-based management. Section 3 is dedicated to the description of the SES and introduces the models and the tested scenarios. Section 4 is dedicated to the modelization results. Section 5 concludes and gives some policy recommendations.

2. From restocking to ecosystem-based management

Eel used to be very abundant in European estuaries and rivers, particularly in France. However, from the 1980s, overfishing – among other causes – led to a continuous decline in stocks, which dwindled to less than 10% of their former level, where they have remained since 2011 (ICES, 2022).

European eels are found over a large area, from Scandinavia to North Africa and across the Mediterranean. They breed in the Sargasso Sea and their larvae migrate across the Atlantic Ocean. The larvae metamorphose into glass eels when they reach the coastal areas (Tesh 2003). Glass eels then colonize a wide range of continental habitats (lagoons, marshes, estuaries, rivers, streams and lakes) (Daverat et al., 2006) where they reach their growth phase, after which they metamorphose into silver eels to migrate back to their spawning area. The oceanic phase of eels is still somewhat of a mystery and their exploitation takes place exclusively during the continental stage of their life cycle.

Eel exploitation has a long history in Europe and developed locally across the entire area in which this fish was found. Eel was therefore integral to the local landscape, along with associated cultural and gastronomic practices (Le Cornec Rochelois, 2022; Le Cornec, 2009). Several periods in history witnessed the rise of more extensive eel trade, for instance between the Dutch and British in the Middle Ages and up until the 18th century. Between 1800 and 1900, more globalized trade took off with even more intensity and demand driven mostly by Germany and the Netherlands, where the strategy was to market eel as a luxury product and social marker (Dekker, 2019). Today still, the German and Dutch markets account for the largest demand for eel products in Europe (FranceAgri Mer, 2022). Since the 1850s, in response to local depletion of overfished eel stocks, restocking programs have been implemented across Europe (Dekker and Beaulaton, 2016). When restocking was undertaken with juvenile eel (glass eels), glass eel fishery activity in France grew from a supply for local food markets to a supply for more distant markets for restocking. Intermediate dealers, called *mareyeurs*, appeared from the 1970s onwards. In the 1980s and '90s, new demand for glass eel arose from Asia (and Japan at the

time), pushing prices up and boosting fisheries once again. Before the 2000s, in terms of financial value, glass eels represented either the largest or the second largest fish market in France (Castelnaud et al., 1994).

Eel restocking thus became intrinsically interconnected with estuary and freshwater fishery activities, including those of fishermen and intermediate fish dealers.

Fishermen target not only glass eels for consumption and restocking, but also yellow and silver eel, though the latter are for consumption only. The majority of catches occur in areas with the largest concentrations: the Bay of Biscay and the Iberian Coast (Aranburu et al., 2016; Bornarel et al., 2018). In France, the majority of elvers are harvested in the Bay of Biscay (ICES, 2019). Glass eel fishing is a highly seasonal activity, limited mainly to the winter (from November to March) and thus allowing fishermen time for other activities during the year. Most glass eel fishers have a different target or other activities outside the season (Castelnaud, 2001): a majority of fluvial fishermen target other diadromous species (shad, salmon, trout, lamprey), and marine fishermen also target other species such as seabass. This multispecies activity implies that the management of glass eel restocking will impact the fishing of other species. Furthermore, the vast majority of elvers sold in the EU originate from French fisheries (FranceAgri Mer, 2022). French elver fisheries, particularly in the Bay of Biscay, are therefore central to both European consumption and species conservation, as they provide the majority of eels used for restocking purposes.

Restocking is now presented as a conservation measure aimed at translocating individuals from one body of water to another with a view to increasing the escapement biomass. However, the effectiveness of such a measure is mainly studied from the perspective of two issues linked to population dynamics and the ecology of the species: survival and growth. The ecological efficiency of restocking as a conservation measure is therefore still in question. (Froehlicher et al., 2023; FranceAgri Mer, 2022).

Even if the ecological benefits of restocking remain unclear, this management measure is still entirely based on wild-caught eels, as the large-scale artificial production of juvenile eels is not possible (Masuda et al., 2012). An ecosystem-based approach can be posited as a win-win on the grounds that maintaining eel population dynamics sustains the economic activity of fisheries, since fishermen are initiating restocking actions (Hanel et al., 2019).

Ecosystem-based management has become the common objective of sustainable fisheries' policy (FAO, 2003; Pikitch et al., 2004; Long et al., 2015). Within this framework, conservation actions involve an ecological management approach that considers the impacts of those actions on several species, rather than managing catches on a species-by-species basis (Hilborn, 2011). Moreover, by addressing social and economic issues alongside ecological ones, the public authorities responsible for managing and preserving threatened or endangered fish species are better able to obtain the collaboration of stakeholders involved in each ecosystem, so as to develop solutions that minimize conflict and improve compliance (Degnbol and McCay, 2007).

An ecosystem-based approach is relevant here because eels belong to a complex socio-economic and ecological system.

During their migration and after their settlement as yellow eels, glass eels are not only prey for marine and estuarine species but are also targeted by maritime and inland fishermen. These fishermen also target other marine, estuarine, and inland species, such as seabass, sole, and silurus, in addition the other lifecycle stages of the eel (yellow and silver eels). From an ecological perspective, adult eels exhibit a versatile predatory behavior, occasionally engaging in scavenging activities (Sporta Caputi et al., 2020). They play a pivotal role as indicator, umbrella, and flagship species in the realm of freshwater biodiversity conservation (Itakura et al., 2020), and represent a valuable biological resource with substantial ecological and socioeconomic significance (Tamario et al., 2019).

3. Material and methods

3.1. SES around restocking in France

Understanding and analyzing the influence of human decisions on the functioning of ecosystems, as well as the feedback effects of the dynamics of ecosystem change on human activities, is the main challenge of research into socio-ecological systems (Ostrom, 2009). The SES framework identifies five main components or variables that form the basis for modelling the complex structure of relationships and the chain of causalities within a SES; it is essential to identify them and to map out their relationships. These components are the resource system, the resource units, the governance systems, the actors, and the focal action situations in which interactions among these components take place to produce SES pathways. These components

also interact with their broader social, economic, and political settings and with other related ecosystems.

In France, the eel's natural habitat is made up of all continental river basins (coastal and non-coastal rivers and associated wetlands), estuarine areas and coastal waters. Therefore, the management of the European eel is organized on the scale of the country's nine major river basin units (BU). Their limits are set by order of the regional prefect, following advice from the Scientific Interest Group for amphihaline fish (GRISAM) and the migratory fish management committee (COGEPOMI), in compliance with the limits set out in the management plan approved by the European Commission (*Plan de gestion des poissons migrateurs. Bassin de la Loire, Côtiers Vendéens et Sèvre Niortaise 2016 partie "anguille"; Plan de gestion anguille de la France*, 2007). Migratory fish are managed at BU scale by the migratory fish management committees (COGEPOMI) which bring together all the stakeholders concerned. They draw up five-year migratory fish management plans (PLAGEPOMI) which stipulate measures to promote the reproduction, development, conservation and circulation of migratory fish species and the conditions for fishing in their respective basins (BU). These support plans include, among other things, local versions of the national eel management plan (*Plan de gestion anguille de la France Rapport de mise en œuvre – juin 2018*). In France, restocking only involves the glass eel stage.

Case study of a river basin unit

The SES that we have developed is based on the socio-ecological realities of the Loire, Vendée coast and Sèvre Niortaise Basin Management Unit (LCVS BU) which is represented in red on the map (Fig. 4.1). More than half of the overall elver fishing quota and the national budget allocated to restocking are allocated to this unit. This BU could also be considered as representative of glass eel fisheries, particularly those developed along the Bay of Biscay (Aranburu et al., 2015; Bornarel et al., 2017). Glass eels were historically the most valuable commercial fish of the Bay of Biscay, before the ban on exports to Asia in 2010 (Feuten et al., 2020). As illegal glass eel fishing is frequent here, this is where the majority of checks are carried out (*Plan de gestion anguille de la France Rapport de mise en œuvre – juin 2018*).

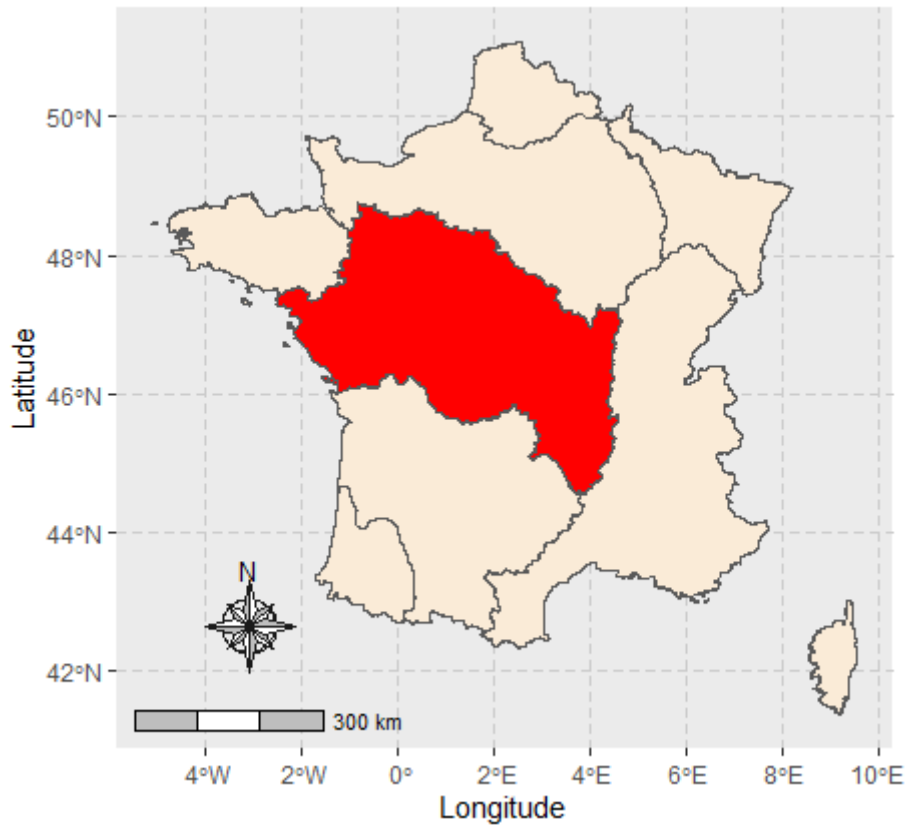


Figure 4.1: map of the different BU in France. The BU LCVS is represented in red.

To guide and inform our modelling approach, and to gain the greatest possible insight and understanding of complex and obscure issues within the SES, we collected information through a questionnaire survey on professional fishermen and formal interviews with fishery managers and fishermen's representatives (Supplementary material S3.1.a). Participant observation of official meetings of the eel fisheries community was integral to the research effort, as it provided a deep dive into the realities surrounding policy issues.

Resource unit

Our resource units include all the resources involved in or affected by eel restocking. First, there are the eels at the various stages of their life cycle, namely glass eel, yellow eel and silver eel, which are directly exploited, as well as the other species caught by glass eel fishermen, primarily seabass (Supplementary material S3.1 (c); CIVECO, 2015).

We distinguish between exploited glass eels and restocked glass eels, which join the wild eel population. Our resource system is built around the fishing activities of the group of fishermen who catch glass eels for restocking. They practice multi-species fishery, in which income from

glass eel accounts for more than a quarter of the total income from fishing in a given year (more than half for some of them). The other targeted species depend on the fishing period and area. Glass eel fishermen can also target lucrative commercial species such as sea bass, sole, cuttlefish and gilthead bream, whether glass eel catches are authorized (from December 1st to April 30th) or not.

With the framework of ecosystem-based management, bioeconomic models of multispecies fisheries have become essential for predicting the evolution of fisheries and the dynamics of ecosystems in relation to their management (Cissé et al., 2013; Jacobsen et al., 2016; Jacobsen et al., 2017; Wo et al., 2020).

Governance

To comply with European Regulation No. 1100/2007, the eel conservation governance tool is an annual harvest quota that is set and distributed across BUs and between river and sea fishermen. The restocking quota has to make up 60% of the total quota. The remaining 40% is allocated to consumption. The Ministry of Agriculture and Food, along with the Ministry of Ecological Transition and Solidarity, steer restocking actions through an annual public call for tenders put out to the organizations that will implement those actions locally. The main objective of this call is to be able to finance these actions through government funding. The costs covered by public budgets include the purchase of glass eels and the monitoring of restocking operations, in addition to management and coordination costs. Given the complexity of the procedure and the transaction costs it generates, only the largest organizational structures, particularly the fishery committees at the level of the *Régions* and the *Départements*, submit tenders. Environmental organizations and local fishermen's associations are therefore excluded from the process. The budget to finance restocking by the local fishery committees is also allocated through a public call for tenders. In this context, it is mainly fish merchants who take part in these public procedures to buy glass eels allocated to restocking directly from fishers. Overall, 5% to 10% of glass eels caught for restocking purposes are returned to their original catch basin unit. The remaining catches are sent to other river basin units or, more generally, exported to other European Member States involved in restocking.

Actors

The complexity of this SES is compounded by the fact that glass eels are targeted not only by maritime fishermen, but also by inland (or river) fishermen. Glass eels are found in the estuaries of the Loire and Sèvre Niortaise Rivers, as well as in the coastal areas of the Vendée, and beyond the administrative saline limit (Danto, 2015). Both management and technical and scientific support for marine fishermen in this management unit is provided by two fishery committees: the Pays de la Loire regional committee for marine fisheries and fish farming (COREPEM) and the Charente-Maritime departmental committee for marine fisheries and fish farming (CDPMEM17). For river fishermen, this role is played by professional fishermen's associations, with the main ones in this management unit being AAPPBLB and AAPPED 44. These bodies issue fishing licenses to professionals, and the fisheries committees require maritime sea glass fishermen to take part in restocking if they want their licenses renewed. As river fishermen are not subject to the same requirement, this causes some tension.

All glass eel fishermen, regardless of the area in which they fish, can join producer organizations (POs) which seek to ensure rational fishing and improve sales conditions for their members. In this management unit, the producer organization with the most glass eel fishermen members is the “Estuaires” PO. Some glass eel fishermen are also members of the “Pêcheurs de Bretagne” PO and the OPPAN. The “Estuaires” PO is particularly important insofar as it has set up storage centers for its members, enabling them to circumvent wholesalers and to store live glass eels before reselling them for restocking or consumption.

The following diagram (Fig. 4.2) summarizes the conceptual framework of the SES surrounding restocking in the LCVS BU, with the resource units, the governance system, and the various actors involved.

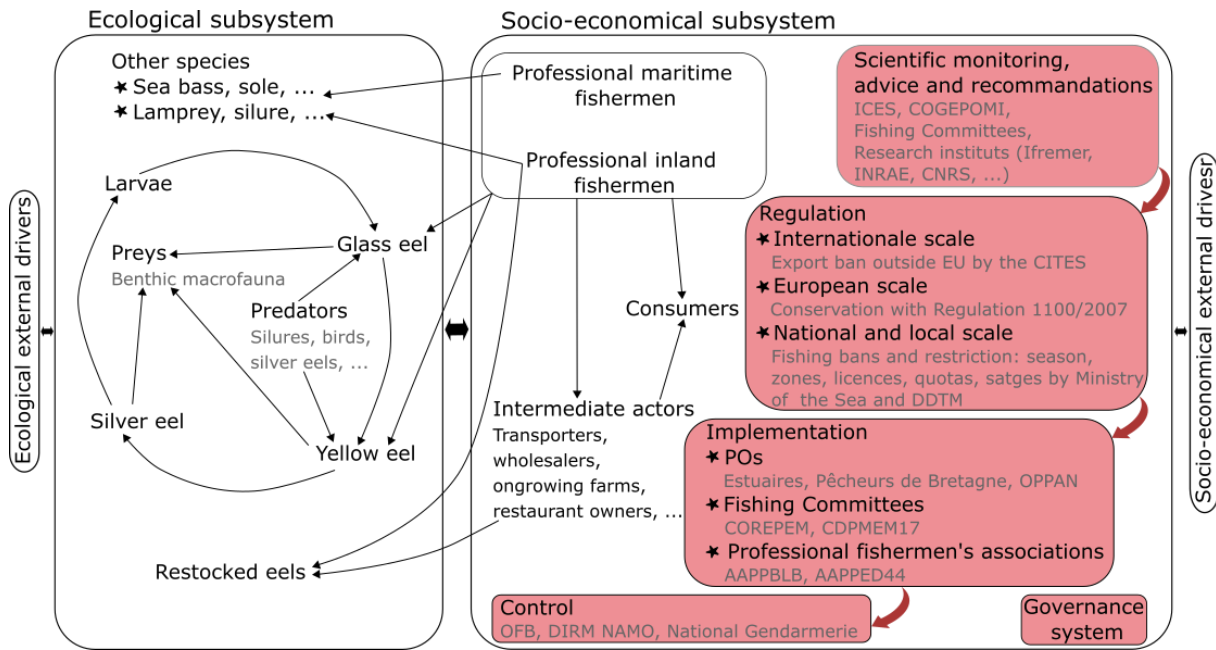


Figure 4.2: Conceptual framework of the SES surrounding the restocking in the LCVS BU, with the resource units, the governance system and the various actors.

Socioeconomic and ecological interactions

Juvenile European eels are mainly harvested in estuarine environments by marine fishermen, at the end of winter and in spring as they migrate from the sea to freshwater. The participation of glass eel fishermen in restocking enables them to generate additional income. During the glass eel fishing season, fishermen also target other species.

Sea bass is the most common species targeted by glass eel fishermen, both during and outside the glass eel fishing season (supplementary material S3.1 (c)). Although catching glass eels requires specific fishing gear (two sieves 1.2m in diameter on boats less than 12m long) with which vessels are equipped throughout the glass eel fishing season, sea bass can be caught year round using various types of fishing gear (often net or hook).

Sea bass is then the main target species for glass eel marine fishermen (either as a replacement or as a supplement), firstly because it is technologically compatible (multi-species fishing), and secondly because sea bass can be fished outside the glass eel fishing season. The total income of glass eel fishermen in this area is therefore largely dependent not only on glass eel catches, but also on catches of other species and primarily of sea bass.

In addition to facing the complex challenge of technical interactions due to the joint exploitation of several species (changes in fishing effort simultaneously affect several stocks), the management of multi-species fisheries is also confronted with the problem of ecological interactions between the different species, as the exploitation of one species has indirect effects on other trophic levels (Agar and Sutinen, 2004; Gourguet et al., 2013; Tromeur and Loeuille, 2017; Tromeur and Doyen, 2018). In the case of the SES of interest here, glass eel juveniles are the prey of other target species such as sea bass, which is a carnivorous predator. Additionally, there is a demand for wild sea bass as consumers seems to prefer wild products rather than farmed ones and the market price for this product remains fairly high (Regnier and Bayramoglu, 2016). Among the target species in this SES, it was also important to find a serious substitute species, that is, a preferred species that would make it possible to reduce glass eel fishing, with a minimal impact on fishers' expected income.

3.2. Qualitative loop modelling

Different applications of the ecosystem-based models ECOPATH with ECOSIM (Heymans et al., 2016), which rely on ecological network analysis, are used to simulate the impact of new regulations designed to support ecosystem-based management approaches (Christensen and Walters, 2004; Colléter et al., 2015; Sreekanth et al., 2021; Rehren et al., 2022). These applications make it possible to infer the extent to which harvest restrictions due to new regulations will result in an increase in the abundance of the target species (Wang et al., 2019). They also show how the dynamics of the target species can lead to the increase or decline of other species (natural predators and prey of the target species), and thus impact the dynamics of many other species in the long run (Sreekanth et al., 2021). However, the ecosystem-based models listed above simplify the impact of regulatory changes on the behavioral responses of fishermen, who may modify their fishing effort or even their target species (Luczkovich et al., 2021). They do not make it possible to distinguish between the direct and indirect effects of regulation, or to explain the causal chains at work (Christensen and Walters, 2004). Loop analysis allows for taking all these direct and indirect impacts into account, including changes in fishermen's behavior, while benefitting from the application of the methodologies offered by network analysis using directed graphs to examine socio-ecological interconnections (Dambacher et al., 2015).

The qualitative model of the SES around eel restocking was based on the structure of a loop model developed by Martone et al. (2017). Their model was able to integrate variables from the ecological and socio-economic dimensions of the SES into a representation that captured them in a balanced way (Rissman and Gillon, 2017), in order to examine the interdependencies between these two dimensions. By combining loop analysis and numerical simulation techniques, their methodological approach enabled them to overcome some of the limitations of a purely qualitative approach (Rodriguez et al., 2021). Finally, such a modelling approach is an alternative to participatory SES modelling methods (Abram and Dyke, 2018) for the integrated assessment of different SES management scenarios.

We translate the conceptual model (Fig. 4.2) into a graphical representation of the main interactions between the components of the SES, which are:

- the resource units (glass eel, sea bass – which is another species targeted by glass eel fishermen –, and the respective catches),
- the stakeholders (glass eel fishermen who may or may not participate in restocking),
- the governance system (application of quotas, regulation of fishing effort, regulation of purchase prices)
- and socio-economic factors (income from fishing).

The loop model of eel populations and sea-bass populations as well as their fisheries qualitatively represents only some selected relationships in the socio-ecosystems studied. This model includes ten variables (Fig. 4.3): RI (Restocking Income); TI (Total fisheries Income); RC (Restocking Catch); RE (Restocking Effort); CE (Consumptive eel Effort); CC (Consumptive eel Catch); GS (Glass eel Stock); SS (Sea-bass Stock); SE (Sea-bass Effort); and SC (Sea-bass Catch). Each variable is represented by a node (large oval) and edges (lines) representing directions and types of relationships: an arrow at one end indicates a positive effect, a circle means the effect is negative, and the lack of a symbol shows a null effect. *Biological links:* Two-species stocks have negative feedback loops to themselves, representing density-dependent effects on population growth rates. Because of their trophic levels, glass eel stocks (GS) have a positive effect on sea-bass stocks (SS) and vice versa. *Socioeconomic links:* as is fairly standard in fisheries, we assume that effort (RE, CE, SE) and stock (GS, SS) have negative effects on each other. In fact, the higher the stock, the lower the effort required to achieve a given catch level. We also assume that stock and effort have positive effects on catch for species that are not under quota regulation or for which the quota is not reached, which is

the case for sea bass (GS, RE, RC) and the restocking of glass eels (SS, SE, SC). As glass eel stock is subject to quotas for restocking and conservation, we assume that catch (RC, CC) has a negative effect on effort (RE, CE). Finally, we assume that effort (CE, RE, SE) has a positive effect on catch (CC, RC, SC), even though this hypothesis is valid only if the stock is not overexploited (*Dynamique de stock*, <https://peche.ifremer.fr>, 2023). We offer an alternative model in which fishing effort for glass eel fisheries (for consumption and restocking: RE, CE) have a negative effect on catch (RC, CC), supposing that the glass eel stock is overexploited (supplementary material S2). As anthropogenic mortality remains poorly documented in the Loire River catchment (Bultel et al., 2014), introducing this alternative model is an interesting complement to our analysis.

As restocking is an additional source of income for fishermen, the income generated by fishermen from restocking (RI) has a positive effect on total fishing income (TI). We also assume that catch (RC, CC, SC) has a positive effect on income (RI, TI) and that income (RI, TI) has a negative effect on effort (RE, CE, SE). However, given the various constraints imposed by the bureaucratic procedure, the variation in the fishermen's overall income (TI) has a negative impact on their participation in restocking (RI).

The model incorporates factors governing the fisheries through a self-damping component that influences both effort and catch. This component symbolizes the impact of variables unaccounted for in the model that can regulate model components (Martone et al., 2017).

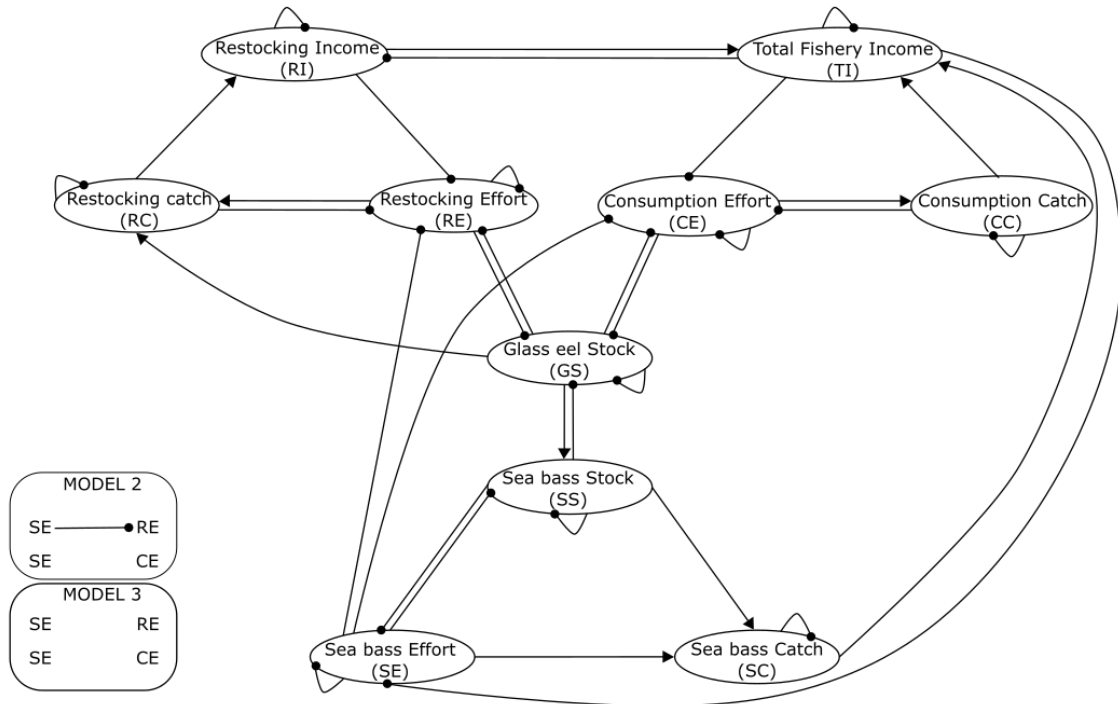


Figure 4.3: The main model (model 1) includes predator-prey relationships between the two stocks – glass eel and sea bass –, and negative relationships between the sea bass and glass eel fishing efforts (for either restocking or consumption).

We therefore explored the effects of two alternative hypotheses on the linkages between these two fisheries, to determine whether the structure of our reference model should be modified or not (models 2 and 3). Remember that in our reference model, sea-bass fishing effort (SE) has a negative effect on both restocking effort (RE) and consumption effort (CE). This type of relationship reflects the joint production properties of multi-species fisheries. In a second model, we have removed the link between sea-bass fishing effort (SE) and fishing effort for glass eels intended for consumption (CE). The third model ignores the technological links between the two fisheries (SE, RE, CE).

3.3. Management scenario testing

Based on the local stability of the system, it is possible to determine the effects of external factors on the variables (Niqui et al. 2021), and to evaluate the effects of different management

scenarios that could complement restocking to improve conservation. However, it is important to stress that the models built and the simulations executed in the present contribution represent the processes underlying the systems studied only when considering short-term dynamics. This limitation of ecosystem models (Ecopath, Ecosim and Loop Analysis) is well known (Ortiz et al., 2013).

From an ecological standpoint, permanent closure of fisheries can facilitate the achievement of conservation objectives for a resource whose stock has collapsed to a critical level (Kaifu et al., 2021). Yet compliance with fisheries closure for nature conservation purposes will depend largely on fishers' acceptance of rules and regulations, and recognition of their legitimacy (Arias, 2015). In addition, very strict regulations are often very difficult to implement, due to the high cost of inspection and control (Mangin et al., 2018). The conservation of endangered species is a complex issue which, if it is to be effective both socioeconomically and ecologically, requires changes in behavior on the part of fishermen, as well as voluntary compliance with regulations (Arias, 2015).

In the fisheries economics literature, fish stocks can be maintained at a target level by various regulatory measures, often referred to as 'traditional regulations', including seasonal or spatial closures of the fisheries to protect juveniles or spawning populations (Oliver et al., 2015), annual harvest limits based on total allowable catches (Clark and Kirkwood, 1986), and limitations on the amount and type of fishing gear used, and on vessel size (Frost and Andersen, 2006). All these regulatory measures are still widely used in commercial fishing regulations (Regulation (EU) No 1380/2013 of the European Parliament and of the Council of 11 December 2013 on the Common Fisheries Policy) and those targeting European eels can be explored (Council Regulation (EC) No 1100/2007 of 18 September 2007 establishing measures for the recovery of the stock of European eel).

We then explore how the SES responds to alternative scenarios of fisheries regulations. We have tested a first scenario which consists in making eel conservation a priority for fishing, and which is expected to lead to lower total allowable quotas for consumer markets. However, the determination of eel prices is a demand-driven process, with the consumptive market prices influencing fishers' supply for restocking, but not vice versa. In this case we can act indirectly by increasing the costs of fishing for consumption, through a fiscal policy that restricts the expected benefits of consumption quotas for wholesalers. The tax revenue can then be used (earmarked) to refund restocking projects. This scenario has also been tested with our models.

In addition, the security of income from eel fishing can also be a concern for the public regulator. To convince fishers to honor their restocking quotas before selling their eels on consumer markets, they can be allowed to benefit from subsidized prices, another scenario we have been tested with our models. Limiting access to fisheries, particularly by allocating a limited number of licenses, follows the simple logic that if the problem is "too many fishermen" for "too few fish", then an obvious solution is to limit the number of fishermen. Another alternative to reduce the fishing effort is to shift it to another species. We have been testing both scenarios with our models.

4. Results

We investigated the responses of single variables to parameter changes in the system by examining the table of predictions for each model. We thus explored the relationships that emerged between the ecological and socioeconomic components, within the three fisheries and five scenarios associated with specific management actions, to determine the response of variables of interest, both biological (stock abundance) and socioeconomic (income). we present below the results obtained with the four models presented above (models 1, 2, 3 and the alternative model).

4.1. Model consistency and validity

Loop analysis allows us to predict how the interactions between variables will evolve on average when a change is induced in the different variables (i.e. a change is induced in the variables in the model several times, and the number of times these changes induce positive or negative changes in the other variables is counted). By doing this, a table of predictions is obtained (Table 4.1).

Table 4.1: Table of predictions. “-“ indicates a negative change (0-25% of relationships are positive); “?-“ indicates a tendency toward a negative change (25-40% of relationships are positive); “?+” indicates a tendency toward a positive change (60-75% of relationships are positive); “+” indicates a positive change (75-100% of relationships are positive); “0” does not represent real zeros. It indicates a neutral outcome that arises when matrices exhibit numerous opposing signs for a specific variable's response. In situations where multiple pathways exert contrary effects on the same variable, the positive*

and negative influences tend to counterbalance each other, potentially leading to a net result of zero (showing no variation) or, more commonly, a minor change that can reasonably be deemed negligible. Predictions are obtained by assuming positive inputs (i.e., increased rates of change of the variables) to the row variables. For tables of predictions of models 2 and 3, see supplementary material S4 and S5.

	GS	CE	CC	RE	RC	SS	SE	SC	RI	TI
GS	+	0*	0*	0*	+	+	-	0*	0*	?+
CE	-	+	+	+	0*	-	0*	-	-	+
CC	0*	-	+	?+	+	+	-	?-	?-	+
RE	-	0*	0*	+	+	-	0*	-	+	+
RC	0*	0*	0*	-	+	+	-	0*	+	+
SS	-	+	+	+	?+	?+	-	?-	?-	?+
SE	+	-	-	-	?-	?+	+	+	?-	0*
SC	-	0*	0*	+	+	0*	-	+	-	+
RI	?-	0*	0*	0*	?-	+	-	-	+	+
TI	-	0*	0*	+	+	0*	-	-	-	+

Looking at these results, it is possible to discuss the coherence and validity of the model. We expected the efforts for consumption and restocking to decrease with an increase of glass eel stock, as a strong population dynamic would support conservation efforts, but this dynamic was not observed in the main model (Table 4.1). It was however observed in the other models, 2 and 3 (Supplementary material S3.4 and S3.5).

Increasing the catch seems to have a less negative impact on stock dynamics than increases in fishing effort. This effect is observed in our four models (Table 4.1 and Supplementary material S3.4, S3.5 and S3.6). It suggests that prioritizing fleet reduction or reducing fishing duration, licenses, and gear might be more effective than lowering quotas. This observation may apply beyond this specific model.

The positive relationship between consumption effort and restocking effort in models 1, 2 and 3 (Table 4.1, Supplementary material S3.4 and S3.5) validates the French hypothesis that maintaining the economic viability of glass eel fisheries supports restocking efforts. Successful conservation cannot be achieved without considering the economics of fishing. However, this

hypothesis is not validated in case of overexploitation, according to the results obtained with the alternative model (Supplementary material S3.6).

When the stock of glass eel increases, the catch for consumption remains stagnant due to the unchanged quota during the 2020-2021 fishing season, assuming a short-term dynamic. This is relevant, considering the highly uncertain long-term dynamic and limited knowledge about replenishment ecology. However, the pattern does not hold for the catch for restocking, which increases, probably due to underutilized quotas throughout the implementation period (Table 4.1).

All four models show that a collapse in the glass eel stock (or an increase in their natural mortality) leads to a reduction in the sea-bass stock (Supplementary material S3.7). This situation seems to lead to a reduction in the catch of glass eels allocated to restocking, and an increase in fishing effort on the complementary species (sea bass).

A collapse in the sea-bass stock also leads to an increase in the glass eel stock. These results are consistent with the trophic levels of the two species (Supplementary material S3.8). In addition, this situation seems to lead to an increase in sea-bass fishing effort. A surprising result of our simulations is that it seems to lead to a decrease in glass eel fishing effort and catches (for both consumption and restocking), while the income allocated to restocking seems to increase and the total fishing income to decrease. The results are all the more surprising in the case of overexploitation of the glass eel stock (Supplementary material S3.8). A collapse in the sea-bass stock appears to lead to an increase in catches of glass eels for consumption and restocking, which is not consistent with the temporality of our model (glass eel catches for consumption cannot increase once the quota has been reached). The model also predicts a fall in effort and catches of sea bass, with a parallel increase in income (whether from restocking or total fishing income).

The results of the alternative model make it possible to discuss those obtained with the basic model developed in this study.

4.2. Predicted outcomes of management actions

Fisheries management actions (scenarios 1 to 3)

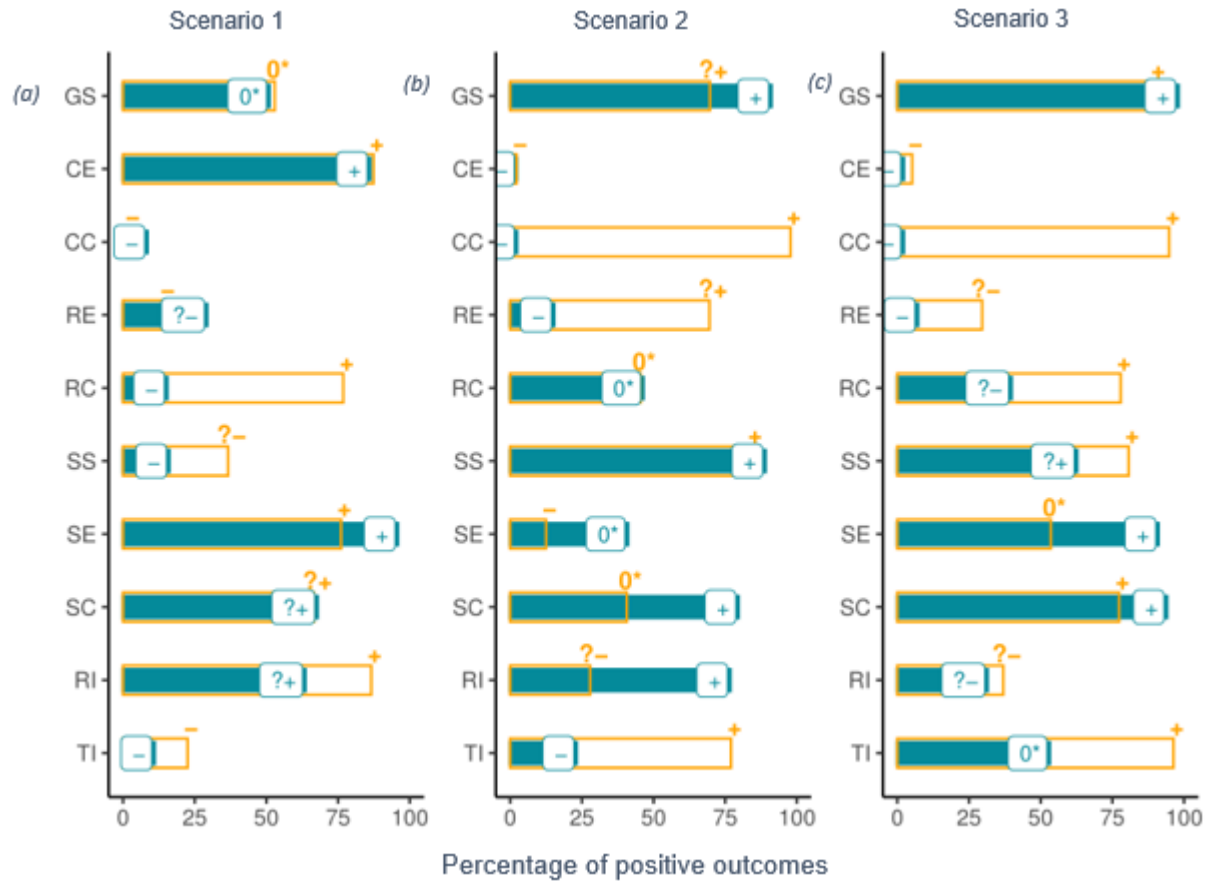


Figure 4.4: Results from loop analysis examining the effects of fishing management actions. Blue bar graphs indicate the percentage of positive outcomes from the model 1 runs. Orange bar graphs indicate the percentage of positive outcomes from the alternative model runs.

In scenario 1, we examined the effect of a decrease in the consumption quota, which is represented by the catch of glass eel for consumption (CC). Glass eel fishing effort for consumption is predicted to increase while catch is predicted to decrease (Fig. 4.4 (a)). Effort and catch for restocking are predicted to decrease. However, the alternative model shows an increase in catch for restocking. Both models predict that this measure would have no effect on the glass eel stock. The sea-bass stock is predicted to decrease with an increase of the effort and catch. Even if the income from restocking is predicted to increase, the global income from fishing is predicted to decrease.

Management measures implemented to reduce in glass eel fishing effort for consumption (CE, scenario 2) are predicted to lead to positive ecological outcomes. Stocks of glass eel and sea bass are expected to increase (Fig. 4.4 (b)). With the exception of the glass eel fishing effect for consumption purposes, which is expected to decrease, and the catch of glass eel for restocking, which is expected to stay at the same level, all the predictions are opposites for both models. While model 1 predicts a decrease of the catch of glass eel for consumption, and of the glass eel fishing effort for restocking, the alternative model predicts an increase of these two variables. The effort for sea bass is expected to stay at the same level with model 1, and to decrease with the alternative model. While the sea-bass catch is expected to increase with model 1, it is expected to stay at the same level with the alternative model. Model 1 predicts an increase in the income from restocking and a decrease in the total income from fishing. The alternative model predicts the exact opposite for this socioeconomic outcome.

Results from this scenario are relatively robust to the representation of the interactions in the system because removing links between fisheries through the fishing effort variable does not change the directional responses of the variables (Supplementary material S3.10).

Supporting the increase in fishing efforts for another complementary or accompanying species, in this specific case, sea bass (SE, scenario 3), would lead to an increase in both glass eel and sea-bass stocks (Fig. 4.4 (c)). Glass eel fishing effort and catch (for both consumption and restocking purposes) are predicted to decrease while those for sea bass are predicted to increase. Concerning the socioeconomic outcomes, income from restocking is predicted to decrease and total income from fishing to stay at the same level. However, the alternative model predicts an increase in glass eel catch (for both consumption and restocking purposes) as well as an increase in the total income from fishing.

Contrary to the previous scenario, the results of scenario 3 must be treated with caution because removing links between fisheries through the fishing effort variable does change the directional responses of the RC and SS variables (Supplementary material S3.11).

Market-based interventions (scenarios 4 and 5)

Figure 4.5: Results from loop analysis examining the effects of market-based management actions. Blue bar graphs indicate the percentage of positive outcomes from the model 1 runs. Orange bar graphs indicate the percentage of positive outcomes from the alternative model runs.

Setting up a direct subsidy for fishermen (RI, scenario 4) leads to an increase in total fishing income (Fig. 4.5 (a)). Despite an increase in glass eel fishing effort and catch for restocking purposes, the income from restocking is predicted to decrease. Glass eel fishing effort and catch for consumption are predicted to stay at the same level, while glass eel stock is predicted to decrease. Sea bass stock is predicted to stay at the same level, while fishing effort and catch of this species are predicted to decrease. Three different outputs are expected with the alternative model: catch of glass eel for restocking is predicted to decrease, as is the stock of sea bass. The fishing effort for sea bass is predicted to stay at the same level.

In scenario 5, we examined the effect of a cross-subsidies' policy which would consist in taxing fish traders in order to finance restocking actions (RI). Such a management measure is predicted

to lead to positive outputs in socioeconomic outcomes (Fig. 4.5 (b)). As for the ecological outcomes, the stock of glass eel is predicted to decrease while the stock of sea bass is predicted to increase. Sea-bass fishing effort and catch are expected to decrease. Glass eel fishing effort (for both consumption and restocking) and catch for consumption are expected to stay at the same level, but glass eel catch for restocking is expected to decrease. The alternative model predicts it staying at the same level.

4.3. Sensitivity analysis

To assess the potential impact of model structure on outcomes, we compared prediction tables generated by the three different models. Our aim was to identify any patterns of concordance among these models. In this analysis, we performed pairwise comparisons of each model's prediction matrix with all other matrices in the series. By doing so, we were able to quantify the instances where a particular prediction matrix exhibited differences from all the others.

Table 4.2:

(a) % difference between the 3 models with tendencies (“?” and “-“)

	Model 1	Model 2	Model 3
Model 1	0	28	33
Model 2	0	0	20
Model 3	0	0	0

(b) After replacing “?” by “+” and “-“ by “-“

	Model 1	Model 2	Model 3
Model 1	0	23	27
Model 2	0	0	11
Model 3	0	0	0

The most significant variance in the frequency of predicted signs among the three considered models occurred between models 1 and 3, showing differences in 33% of all pairwise

comparisons. On average, when comparing the three models, different signs were observed in 27% of cases (Table 4.2 (a)). However, if we treat sign tendencies (e.g. “?+” and “?-“ predictions) as actual signs (“+” and “-“ respectively), the differences become less pronounced. Models 1 and 3 remain the most dissimilar, but their predictions differ in only 27% of comparisons, and the average difference among models reduces to 20% (Table 4.2 (b)). Thus, the structure of the model can influence outcomes, but the occurrence of distinct predictions is limited in a small fraction of simulations. This suggests that the outcomes can be considered relatively robust against changes in the model structure that were tested.

5. Discussion

Before discussing the results, we would like to point out that the model we have created is experimental and is intended to be improved. The model represents a spatially and temporally restricted SES. The aim is to use this initial case study as a decision-making tool, which can be used on other spatial and temporal scales and developed further. For example, as we deal with a multi-species fishery, more variables could be introduced for other exploited species. We chose here to include only one of the most emblematic species of this multi-species fishery because sea bass is targeted by marine and inland fishermen throughout the year. Therefore, effort and catch variables could also be attributed to the different types of fishermen (marine, inland, or even recreational).

According to our results, some management measures could lead to the fishing effort shifting to the complementary species. This situation might have several effects, one of them being the collapse of the species stocks concerned, which is what we observe in the first scenario. Therefore, decreasing the consumption quota should be promoted with caution.

Determining whether the glass eel stock is overexploited or not is crucial to the implementation of management policies with different outcomes. The French hypothesis that maintaining the economic viability of the glass eel fishery supports restocking efforts is valid only if we are not dealing with a case of overexploitation. This hypothesis may be seriously called into question when looking at the ICES scientific advice, which recommends stopping glass eel fishing (ICES, 2022), whether for consumption or for restocking – a recommendation that the authorities have chosen not to implement. More generally, and even if some localized eel stocks are not overexploited (Aprahamian and Wood, 2021), scientists are pointing to a collapse in the European eel population (Henderson et al., 2012; Aschonitis et al., 2017), explained by changes

in oceanographic and atmospheric factors (Baltazar-Soares et al., 2014; Drouineau et al., 2018). Following the collapse, the eel population's ability to recover has been hampered not only by low recruitment, but also by the effects of a multitude of anthropogenic impacts. There is therefore an urgent need to drastically reduce or even stop the sources of anthropogenic glass eel mortality, primarily fishing and pumping for power generation (Aschonitis et al., 2017; Beaulaton and Briand, 2007).

Our modelling has shown that it is particularly important to determine the status of this stock, insofar as it can lead to opposite effects for several management measures. The main model shows no scenario with positive outputs for either ecological or socioeconomic variables. However, the alternative model, based on overexploitation of the glass eel stock, shows positive outputs for scenarios 2 and 3. Reducing the glass eel fishing effort for consumption, or supporting an increase in fishing effort targeting another complementary or accompanying species, not only benefits the glass eel stock but also positively impacts the stock of the accompanying species. Furthermore, it has a favorable effect on fishermen's income overall. These results must nevertheless be considered with caution.

Concerning the third scenario (increasing the fishing effort targeting sea bass as a complementary species), we chose sea bass as the main accompanying species. However, although this species is not threatened, it is currently under regulation in the area of interest (*Arrêté du 4 juillet 2023 modifiant l'arrêté du 17 janvier 2019 relatif au régime national de gestion pour la pêche professionnelle de bar européen (*Dicentrarchus labrax*) dans le golfe de Gascogne (divisions CIEM VIII a, b)*) even if the state of the stock is stable and at a level that will enable it to achieve maximum sustainable yield (MSY) according to ICES advice since 2020 (ICES, 2023). An alternative accompanying species could be mullet, including the thinlip grey mullet (*Chelon ramada*) or the thicklip grey mullet (*Chelon labrosus*). This substitution might be advantageous because mullet species are opportunistic feeders. Adults feed on fresh or detrital plant material, microphytobenthos but also on meiofauna (Lebreton et al., 2011), which could have positive environmental implications. Additionally, the fishing period for mullet seems to align with that of sea bass (supplementary material S1.3), and can thus be justified as a suitable replacement. It is also said that its flesh is similar to that of sea bass (Bacchi et al., 2020). Although it is less well known to consumers, the increase in landings in recent years is a sign that this species, which has a low market value, is gaining ground on the market. The current price of thicklip grey mullet is around €8.5/kg, whereas that of sea bass can rise up to more than €30/kg (<https://rnm.franceagrimer.fr/prix>, 2023). However, this difference

in value shows that we are dealing with two different types of goods. These products are targeted by consumers with different profiles, and the effects on fishermen's incomes will not be equivalent if a management measure is set up to shift part of the fishing effort from glass eel to sea bass or mullet. Moreover, as there is no scientific monitoring of mullet species, the state of stocks and their exploitation is still totally unknown (Bacchi et al., 2020).

The second scenario (reducing the glass eel fishing effort for consumption purposes), while theoretically sound, is challenging when it comes to practical implementation. Reducing the glass eel fishing effort for consumption purposes without inadvertently decreasing the fishing effort for restocking is a complex task. A decrease in the consumption fishing effort could lead to an automatic reduction in the restocking fishing effort and vice versa, as the same fishing gear, boats and licenses are used. To separate the fishing schedule could be an alternative solution. For now, the consumption quota is filled first, and the restocking quota is not used up (based on data from the assessment of glass eel campaigns, drawn up on the basis of declarations from wholesalers). The target set by the EU has therefore not been met, strictly speaking, since catches allocated to restocking do not account for 60% of all catches. An option could be to start the fishing season by allowing the catch of glass eels for restocking before allowing it for consumption. A more drastic option could be to allow the catch of glass eel for consumption only if an individual quota for restocking is filled.

To implement such a measure, individual quotas would have to be systematically introduced instead of a collective quota as is currently the case. Quotas are split between marine and inland fishermen, and then between BUs based on their respective track records (previous catches over reference years). There is an exception for the LCVS BU, where quotas are divided between members of the "Estuaires" PO and non-members (*Arrêté du 20 octobre 2022 portant définition, répartition et modalités de gestion du quota d'anguille européenne (Anguilla anguilla) de moins de 12 centimètres pour la campagne de pêche 2022-2023*). The PO then decides how the quota allocated to them will be distributed among its members. In the scientific literature, collective quota measures have not received as much attention as individual fishing quota (IFQ) or individual tradable quota (ITQ) measures (Zhou and Sergerson, 2016).

Within the framework of a shared quota, when a fisherman uses a portion of the collective quota, the quantity available for others is reduced. Consequently, a fisherman's opportunities are shaped by the decisions made by fellow fishermen. A hypothesis is that, irrespective of whether these interdependencies are driven by factors internal to the fishery or are the result of

external global constraints only, the collective allocation of rights or limits motivates group members to collaboratively address these interdependencies (Zhou and Sergerson, 2016). Under certain circumstances, with favorable conditions for collective action, encouraging results have been recorded (Peña-Torres et al., 2019).

Another challenge associated with the restocking quota relates to market opportunities.

Fishermen are expressing concerns because they are encountering difficulties in selling the fish for restocking and are advocating for a portion of the restocking quota to be redirected towards consumption (<https://lemarin.ouest-france.fr>, 2023). At the same time, there is an issue of illegal export of elvers to Asian countries, where they are sold at premium prices (Stein et al., 2016).

We have also noticed disparities between professional sea and freshwater fishermen, since in the UGA we are interested in, sea fishermen must contribute to restocking in order for their fishing license to be renewed, whereas this is not the case for freshwater fishermen. These disparities can exacerbate inter-category tensions within the fisheries.

Despite these considerations, fishermen seem to consider restocking as quite an effective management measure for restoring eel stocks (supplementary material S1.5). Of the eight measures listed in European Regulation No 1100/2007, restocking, improving connectivity, and temporarily shutting down hydroelectric turbines seem to be the most popular among professional eel fishermen (supplementary material S1.5). Restocking is supported more by fishermen targeting glass eel, whereas the opposite is true for the other two measures. It is clearly the oldest fishermen who are most in favor of these three measures (supplementary material S1.5).

Beyond the scenarios tested using modelling, the ecosystem-based approach is still challenging for large migrating aquatic species. The governance of their fisheries involves a complex landscape, characterized by the coexistence of numerous highly localized stakeholders alongside centralized decision-making organizations, in addition to the various habitats in which these species live throughout their life cycle (Danto, 2021; Aas, 2018).

In the realm of fisheries management, the conventional administrative approach to regulating fishing activities is coming under growing scrutiny, particularly for its perceived imposition of top-down measures that often seem disconnected from the realities on the ground. This disconnect has been highlighted in fishermen's responses to our questionnaire, where they express frustration at the impact of regulations on their fishing activities.

To conclude, through our modelling we have identified scenarios that appear to be ecologically and socio-economically viable, all of which involve implementing measures to reduce fishing pressure on the elver resource. However, it is essential to critically assess the implications of these scenarios, especially when they imply shifting the fishing effort to complementary species that may also be under pressure. Moreover, the broader context of restrictions surrounding elver fisheries does not seem to establish a foundation for sustainable fishing practices. The issues of excessive catches relative to demand and unfavorable pricing exacerbate tensions among industry professionals, regulatory bodies, and the scientific community.

CONCLUSION

*« Les enjeux et les possibilités de l'interdisciplinarité
se rejouent pour chaque objet et pour chaque situation »*

*Anthony Pecqueux, Perrine Poupin et Jean-Baptiste Vuillerod,
Aventures de l'interdisciplinarité : les sciences de la nature et
les sciences humaines et sociales face à la question écologique, 2022*

General discussion and outlook

1. Summary of the main results

By creating dialogue between disciplines and stakeholders throughout this thesis, I have embraced three distinct methodologies that have allowed me to analyze data of different natures. These methodologies have facilitated the exploration into multiple facets of the social-ecological system concerning eel restocking and conservation. The aim was to provide answers regarding the effectiveness of restocking as a conservation measure. The first ambition was to assess its ecological effectiveness by investigating the state of the art. The aim was also to provide insights into potential future demand management scenarios, benefiting governance stakeholders in eel-consuming and importing nations, but also, to offer scenarios for future fishing management, enlightening governance actors in eel-producing and exporting countries.

In the **first chapter**, the ecological effectiveness of eel restocking as a conservation translocation action was called into question. Scientific work conducted and published on the subject highlighted significant knowledge gaps notably due to the limited understanding of the oceanic phase of the eel life cycle, with studies predominantly focusing on the continental phase. Furthermore, while ecological processes related to eel translocation had been studied during this life cycle phase, there were still research gaps. For instance, the survival and growth of translocated individuals were not compared to those of wild eels. Additionally, community-level research on predation of restocked eels and their impact on translocation areas remained scarce. This chapter also revealed the ambivalence of eel restocking, intended as a conservation measure but also driven by economic considerations. Some authors have warned against such situations (Germano et al., 2015; Novak et al., 2021) and I concur with their conclusions. The "argumentum absurdum" reasoning presented in this chapter illustrates that eel translocation actions do not cumulatively optimize species fitness during the continental phase of its life cycle.

The socio-economical aspect of restocking, and widely eel production, emerged as a key component of the socio-ecological system that interested me in this thesis. In the **second chapter**, eel conservation was approached from the perspective of historical consumers of this species. An economic valuation was conducted in order to identify socially appealing policy interventions for the conservation of threatened eel species in Japan. The discrete choice experiment revealed that Japanese eel consumers seemed to want to leave the status quo regarding mixed policy instruments for eel species conservation in Japan. They showed interest

in awareness campaigns, labels, and the substitution of eel consumption with other species such as conger eel, sanma, or catfish. Regarding preference heterogeneities, three consumer classes were identified among Japanese eel consumers. The first group, or the "liberal conservationists," was the least pro-environmental class but still sought to depart from the status quo, preferring market-oriented instruments. The "environmental skeptics" constituted the second class, prioritizing the status quo despite their relatively pro-environmental behavior compared to the first class. The third class, or the "responsible consumers," favored demand-regulation instruments, such as price increases or quantity reductions. This class exhibited varied environmental affinity profiles. Our empirical analysis revealed that individual knowledge and environmental concerns played an ambiguous role in shaping preferences for both coercive and non-coercive policy instruments.

In the **third chapter**, the ambition was to study the complete socio-ecological system surrounding eel restocking as a conservation action within a specific case study: the Loire, Vendée coast, and Sèvre Niortaise Basin Management Unit. Various components of the SES and its subsystems were described, along with their interactions. The previous chapters demonstrated that restocking alone is insufficient for rebuilding the eel population. To conserve and use eels sustainably, demand regulation measures are necessary and expected by consumers. Therefore, I aimed to test the ecological and socio-economic viability of five fishing management scenarios in complement of restocking. Using the qualitative loop analysis based on the described SES, I highlighted that implementing management measures to reduce glass eel fishing effort was the best alternative for reconciling robust socio-economic dynamics for fishermen and to maintain, or even restore, the European eel population.

2. Is it desirable to maintain a glass eel economy in France?

During my thesis, the situation has undergone significant changes, especially in Europe, following the ICES's advice released in November 2021 that disrupts the balance –if balance there were- between the exploitation and conservation of European eels. The group of scientists advocated for a zero-capture policy in all habitats and for all life stages, encompassing both recreational and professional fishing purposes (ICES, 2021). This marks a clear departure from previous advice, which emphasized to minimize anthropogenic impacts and maintain them close to zero, signifying that scientific experts no longer believe in accommodation between exploitation and conservation of European eels.

Now, the question arises regarding the potential socio-economic impact that a fishing ban might have on professional fishermen. The results from my survey in LCVS BU presented in **chapter 3** (Supplementary material S3.1 (d)) revealed that for fishermen targeting glass eels, the catch of this stage of eel life cycle contributes to 30-60% of their income, which amounts to €70,000 to €100,000 annually. Approximately 60% of the income from glass eel fishing comes from sales for consumption, while about 40% comes from sales for restocking. Restocking therefore carries less economic weight than the consumer market. Although the fishery is multi-species, the economic weight of glass eels appears substantial. A complete ban would have a notable impact on fishermen's income, but this warrants further investigation due to the lack of socio-economic data.

According to the results of the qualitative model in the second chapter, it seems entirely reasonable from a socio-economic standpoint to implement more restrictive fishing effort management measures. The findings indicate positive effects on fishermen's incomes and on the stocks of the multi-species fishery. While this model requires further development, particularly by incorporating other target species, the results are encouraging. Rather than focusing management on capture-related measures such as quotas, which negatively affect fishermen's income, we offer measures to reduce and/or shift fishing effort towards complementary species such as seabass or mullet.

In the same time, an issue regarding the demand for restocking seems to emerge in the grey literature: there might be a lack of outlets for these restocking glass eels. While such measures are imposed in certain BU, the restocking market appears unreliable for fishermen. Moreover, it seems there is an imbalance with this obligation which might only concern marine fishermen but not inland fishermen in certain BU. Thus, despite good intentions in implementing these measures initially aimed at sustaining both eel populations and fishermen's activities, it seems that neither of these objectives is genuinely achieved. The restocking strategy maintains an unstable socio-economic dynamic and fails at restoring the eel population, as shown in **chapter 1**.

So, what about a fishing ban? The Sustainable Eel Group (SEG) raised the issue of the impact a ban might have on poaching and illegal trafficking in an answer they gave to the ICES advice (2021). It is true we do not have any evaluation of the subject but, at least, the ambiguity surrounding the fact that eels destined for restocking could fuel illegal trafficking would disappear and the traceability system would not be a problem anymore. If catch for conservation

and restocking persists, it should be acknowledged that it significantly complicates trade control and necessitates enhanced monitoring efforts.

One can also question the decision to ban exports, considering the impact on other eel species. As mentioned in the introduction, the consumption of East Asian countries has shifted to other eel species including tropical species. While this thesis focuses on temperate eel species in the Northern Hemisphere, future research should also address these tropical species, including *Anguilla bicolor*, for which many uncertainties remain regarding its demand in East Asian countries (Shiraishi, 2020). Instead of focusing the whole policy management on market-oriented instruments why not invest more efforts in demand-regulation instruments, which appears to be at the heart of the problem, as demonstrated in **chapter 2**?

To go further, the question of sustaining the glass eel economy in France should be considered within a global and broader context as the distribution area is vaster than EU borders and the consumption predominantly occurs in Asia. The importance of strong cooperation among eel-hosting countries, whether within or outside the EU, has been emphasized in reports by MNHN (2014) and TRAFFIC (Shiraishi, 2020). Some authors had already proposed more integrated management, at least among East Asian countries, during the ban era (Tsukamoto et al., 2009).

3. Are we seeing the emergence of more global environmental concerns about biodiversity conservation?

The results from **chapter 2** are promising, as they demonstrate that environmental concerns are prevalent among consumers. However, it is crucial that individuals not only exhibit pro-environmental consumption but also support conservation policies. Combining these actions can lead to sustainable fisheries and more effective conservation of threatened species. In **chapter 2**, a specific group of consumers raises questions: those who preferred not to alter their eel consumption. Strangely, these individuals exhibited a high level of environmental knowledge and sensitivity, believing it is important to maintain the balance of nature. This paradoxical situation merits further exploration. In this discussion, I offer some avenues for reflection.

Although values conflicting with the prevailing mindset are often rejected, in specific cases, information or values can coexist, even when contradictory (Nguyen and Jones, 2022). This occurs when individuals perceive both sets of values as beneficial. Japanese citizens may consider preserving nature as essential, but the consumption of eel is still seen as conferring

other benefits, such as nutritional value, health, or taste. The concept of "cultural additivity" might help understand these paradoxes and could be studied in the context of consuming threatened species (Nguyen and Jones, 2022). This concept describes a mechanism whereby individuals are willing to incorporate values and norms from other belief systems into their culture, even if they logically contradict their existing beliefs (Khuc, 2023).

These consumers might also believe that it is not their responsibility but rather the government's duty to be more effective. This situation is related to a psychological mechanism of moral disengagement (Wu et al., 2021) in which individuals attribute blame to others or to the context. The dehumanization mechanism, wherein an individual's internal moral norms are less likely to be activated if the behavior in question is defined as morally irrelevant (Wu et al., 2021), might also explain this paradox. In our case, it could be related to the tradition associated with eel consumption in Japan.

Lastly, it is worth noting that our case study is unique in that Japanese consumers purchase the product in a processed form. This could indicate a lack of connection with the primary product i.e. wild eel, and might explain why the group of interest includes younger consumers, who may not have had the same level of contact with the species as older generations as the local species has been declining.

In any case, the consumer preferences studied among Japanese consumers in this thesis could be expanded to encompass all eel consumers, particularly those in China.

I also pondered how eel conservation is perceived in countries where it is heavily fished. It is possible that the relationship with eel differs, with Japanese consumers being closer to the product, whereas the French citizens potentially have a closer connection to the animal. I focused on France and citizens' preferences regarding the management of the critically endangered European eel species. Citizens who contribute to financing these actions through taxes, for example, may legitimately question the sustainability of conservation measures, such as restocking, which could ultimately justify further pressures on the resource and the maintenance of direct resource exploitation. Moreover, it could fuel a black-market trade to Asian countries. I therefore conducted an online survey, disseminated by the CPA company in August 2022, among French citizens, gathering responses from 1,211 participants (Supplementary material S4.1). The survey was evenly distributed across 8 of the 9 French management units (Supplementary material S4.1 and S4.2) and in communes based on the four density levels defined by INSEE (<https://www.insee.fr/>, 2023; Supplementary material S4.1).

The questionnaire was constructed on the same basis as the one sent to Japanese consumers in chapter 2, including questions on socio-demographic parameters, environmental attitudes, attitudes towards European eels, and perceptions of eel conservation (Supplementary material S4.3). I also presented the context in video format, offering additional information to half of the respondents (Supplementary material S4.4). The scenarios' attributes and levels are summarized in supplementary material (S4.5). One objective of this choice was to test the French citizens preferences regarding the zero-catch scenario introduced by the ICES advice (2021).

I did not have the opportunity to analyze this data, but it opens exciting prospects for future research. A parallel view between the results of this survey and results from **Chapter 2** would be interested in addition to enable a direct comparison of environmental sensitivities and concerns regarding the conservation of threatened species.

4. Conclusion

I finished my manuscript introduction by discussing interdisciplinarity as a challenge in thesis, and I would like to conclude this it by revisiting this point. In the end, I consider this thesis as a sort of mini laboratory for interdisciplinarity, in which I endeavored to leave the door open for various fields of knowledge. The aim was to make this work accessible not only to ecologists and to environmental economists, but also to various stakeholders, providing answers to the management of threatened species. Once again, I emphasize that an interdisciplinary project, whether within the scope of a thesis or not, requires the collaboration of researchers from diverse backgrounds who are capable of communicating about their disciplines, listening, and making an effort to understand their colleagues. Finding myself at the intersection of these worlds has been a source of enthusiasm and intellectual pleasure as much as it has been a cause of anxiety. I probably owe my first gray hairs to this situation. I must reiterate that this thesis would not be what it is without the initial determination of Tina and Françoise to blend their two realms of expertise by involving me in this reflection, before I delved into this captivating subject four years ago. As we have seen, the integration of stakeholders, governance, and scientific disciplines is more necessary than ever to comprehend the complex questions and challenges related to the biodiversity crisis we are currently facing.

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Supplementary material

Chapter 1 (S1)

S1.1. Keywords

(resettlement OR restock* OR translocat* OR transfert OR aquaculture OR stock* OR introduc* OR redistribution)

AND

((eel OR "glass eel*" OR elver*) AND ("Anguilla" OR "Anguilla japonica" OR "Anguilla rostrata"))

AND

((geneti* AND (predisposition* OR plasticit*)) OR survi* OR mortalit* OR fitness OR croissance OR growth OR "sex ratio" OR fecondity OR reproduction OR density OR "carrying capacity" OR competition OR predation OR "ecological function*" OR migration OR orientation)

AND

(efficien* OR effectiveness)

AND

(lake OR river OR watershed OR catchment)

S1.2. Large corpus (Zotero)

The link bellow will give you access to the large corpus on Zotero:

[..\Large corpus.rdf](#)

S1.3. Leximancer parameter setting

We first applied the default settings of Leximancer: measurement of the co-occurrence of concepts in two sentences of the same paragraph, auto-paragraphing, and the automatic identification of concepts. The concepts that were not central to the study or meaningless were then removed manually, and some words that were very similar (particularly in semantic terms) were merged and new concept statistics and maps were required by Leximancer. Leximancer produces relevance scores, which are the percentage frequency of two-sentence blocks coded with that concept relative to the frequency of the most frequent concept. These scores were used

to indicate the relative strength or significance of a concept's frequency. The visualization of interrelationships between concepts in the form of a concept map focused on themes, that is, concepts that do not illustrate habitats, life cycle stages or species (see list under Fig. 4).

FINAL COMPLETE LIST

- Mix of the list automatically generated and the list generated with the 1,000 most relevant concepts
- The concepts to retain for the analysis are selected (some do not mean anything, others are too vague or not sufficiently relevant)
- Similar concept seeds are merged (for example, concepts "adult" and "adults")
- We merged manually the concept of "restocking" with 5 other concepts related to the word "translocation" ("translocation", "translocated", "translocate", "translocates", "translocating")

Concepts	Merged concepts
adult	<i>adults</i>
age	<i>aged</i> <i>ages</i> <i>aging</i>
rostrata	<i>anguilla</i> <i>anguilla's</i>
crassus	
anthropogenic	
aquaculture	
artificial	<i>artificially</i>
assessment	<i>assess</i> <i>assessed</i> <i>assesses</i> <i>assessing</i> <i>assessments</i>
bacterial	
behavior	
behaviour	<i>behaviors</i> <i>behaviours</i>
biomass	
blood	<i>bloods</i>
body	<i>bodies</i>
brackish	
brain	<i>brains</i>
cadmium	
captured	<i>capturability</i> <i>capturable</i> <i>capture</i> <i>captured</i> <i>captures</i>

	<i>capturing</i>
catch	<i>catches</i>
	<i>catching</i>
	<i>caught</i>
catchment	<i>catchments</i>
cell	<i>cells</i>
	<i>cell's</i>
	<i>cellular</i>
chemical	<i>chemicals</i>
coast	<i>coasts</i>
	<i>coastal</i>
	<i>coastals</i>
commercial	<i>commercialization</i>
	<i>commercialized</i>
conservation	<i>conservation's</i>
	<i>conserved</i>
	<i>conserve</i>
	<i>conserving</i>
consumption	<i>consumptions</i>
contaminants	<i>contamin</i>
	<i>contaminant</i>
	<i>contaminate</i>
	<i>contaminated</i>
	<i>contaminates</i>
	<i>contaminating</i>
	<i>contamination</i>
	<i>contaminations</i>
	<i>contaminated</i>
continental	
culture	<i>Cultured</i>
	<i>cultures</i>
dam	
damage	<i>damaged</i>
	<i>damages</i>
	<i>damaging</i>
density	<i>densities</i>
diet	<i>dietary</i>
	<i>diets</i>
	<i>fed</i>
	<i>feed</i>
	<i>feeds</i>
	<i>feeding</i>
	<i>food</i>
	<i>foods</i>
disease	<i>diseased</i>
	<i>diseases</i>

Supplementary material

distribution	<i>distribute</i> <i>distributed</i> <i>distributes</i> <i>distributing</i> <i>distribution</i> <i>distributions</i>
downstream	
ecological	<i>ecologic</i> <i>ecology</i>
eel	<i>eels</i> <i>eel's</i> <i>anguillid</i> <i>anguillids</i>
efficiency	<i>efficiencies</i> <i>efficient</i> <i>efficiently</i>
egg	<i>eggs</i> <i>egg's</i>
elver	<i>elvers</i>
energy	<i>energies</i>
environment	<i>environments</i>
environmental	<i>environmentally</i>
escapement	<i>escape</i> <i>escaped</i> <i>escapements</i> <i>escapes</i> <i>escaping</i>
estuary	<i>estuarial</i> <i>estuaries</i> <i>estuary's</i> <i>estuarine</i> <i>estuarines</i>
european	
exposure	<i>exposures</i> <i>exposed</i> <i>expose</i> <i>exposes</i> <i>exposing</i>
farm	<i>farmed</i> <i>farming</i> <i>farms</i>
fat	<i>fats</i> <i>fatty</i>
female	<i>females</i> <i>female's</i>
fishermen	

Supplementary material

fisheries	<i>fishery</i> <i>fishery's</i> <i>fishing</i>
freshwater	<i>freshwaters</i>
gene	<i>genes</i> <i>genetic</i> <i>genetical</i> <i>genetically</i> <i>genetics</i> <i>genome</i>
gill	<i>gills</i>
glass	
gonad	<i>gonadal</i> <i>gonads</i>
growth	<i>growths</i> <i>growing</i>
habitat	<i>habitat's</i> <i>habitats</i>
hatching	<i>hatch</i> <i>hatched</i> <i>hatches</i> <i>hatchings</i>
health	
hepatic	
hormone	<i>hormonal</i> <i>hormones</i>
immune	<i>immunities</i> <i>immunity</i> <i>immunization</i> <i>immunize</i> <i>immunized</i>
individual	<i>individuals</i> <i>individual's</i>
infection	<i>infected</i> <i>infections</i> <i>infecting</i> <i>infect</i> <i>infects</i>
inland	<i>inlands</i>
intestinal	<i>intestine</i> <i>intestines</i>
japonica	
juvenile	<i>juveniles</i>
lagoon	<i>lagoons</i> <i>lagoonal</i>
lake	<i>lakes</i>

Supplementary material

larvae	<i>larva</i> <i>larva's</i> <i>larvae's</i> <i>larval</i>
length	<i>lengths</i>
leptocephali	
liver	<i>livers</i>
long-term	
magnetic	
male	<i>males</i> <i>male's</i>
management	<i>manage</i> <i>manageable</i> <i>managed</i> <i>managements</i> <i>managing</i>
marine	<i>marines</i>
maturation	<i>maturated</i> <i>maturing</i> <i>maturations</i> <i>mature</i> <i>matured</i> <i>matures</i> <i>maturing</i> <i>maturity</i>
metabolism	<i>metabolic</i>
metabolites	
metal	<i>metals</i>
metamorphosis	
migration	<i>migrate</i> <i>migrated</i> <i>migrates</i> <i>migrating</i> <i>migrational</i> <i>migrations</i> <i>migratory</i>
mortality	<i>mortal</i> <i>mortalities</i>
movement	<i>movements</i>
muscle	<i>muscled</i> <i>muscles</i>
nematode	
net	<i>nets</i> <i>net's</i> <i>netting</i>
ocean	<i>oceanic</i>

	<i>oceans</i>
oocyte	<i>oocytes</i> <i>oocyte's</i>
organs	<i>organ</i>
origin	<i>originate</i> <i>originated</i> <i>originates</i> <i>originating</i> <i>origins</i>
otolith	<i>otoliths</i>
ovarian	<i>ovary</i> <i>ovarial</i> <i>ovaries</i>
parasite	<i>parasites</i> <i>parasitism</i> <i>parasite's</i> <i>parasited</i> <i>parasiting</i>
pesticides	
plasma	<i>plasmas</i>
polluants	<i>polluant</i> <i>pollution</i> <i>pollutions</i> <i>pollute</i> <i>polluted</i> <i>pollutes</i> <i>polluting</i>
pond	<i>ponds</i>
population	<i>populate</i> <i>populated</i> <i>populating</i> <i>population's</i> <i>populations</i>
production	<i>product</i> <i>productions</i> <i>productive</i> <i>productivities</i> <i>productivity</i> <i>products</i> <i>produced</i> <i>produce</i> <i>produces</i> <i>producing</i>
protection	<i>protect</i> <i>protected</i> <i>protecting</i>

Supplementary material

	<i>protects</i>
quality	<i>qualities</i>
recruitment	<i>recruited</i>
	<i>recruiting</i>
	<i>recruitments</i>
	<i>recruits</i>
release	<i>released</i>
reproduction	<i>reproductions</i>
	<i>reproductive</i>
	<i>reproductivity</i>
restocking	<i>restock</i>
	<i>restocks</i>
	<i>restocked</i>
	<i>restockings</i>
	<i>stocked</i>
	<i>stocking</i>
	<i>stockings</i>
	<i>translocation</i>
	<i>translocated</i>
	<i>translocate</i>
	<i>translocates</i>
	<i>translocating</i>
river	<i>rivers</i>
	<i>river's</i>
salinity	<i>salinities</i>
	<i>salt</i>
	<i>salted</i>
	<i>slating</i>
	<i>salts</i>
salmon	<i>salmonids</i>
	<i>salmonid</i>
	<i>salmons</i>
sea	<i>seas</i>
seawater	<i>seawaters</i>
sex ratio	
sexual	<i>sexuality</i>
silver	<i>silvered</i>
	<i>silvers</i>
silvering	
size	<i>sized</i>
	<i>sizes</i>
	<i>sizing</i>
spawning	<i>spawn</i>
	<i>spawned</i>
	<i>spawning</i>
	<i>spawnings</i>

	<i>spawns</i>
sperm	<i>sperms</i>
stock	<i>stocks</i>
stream	<i>streaming</i>
	<i>streams</i>
stress	<i>stressed</i>
	<i>stresses</i>
	<i>stressful</i>
	<i>stressing</i>
survival	
swimbladder	<i>swimbladders</i>
temperature	<i>temperatures</i>
thyroid	<i>thyroidal</i>
tidal	<i>tidally</i>
tissue	<i>tissues</i>
toxic	<i>toxicity</i>
	<i>toxicities</i>
trout	<i>trouts</i>
upstream	
virus	<i>viruses</i>
weight	<i>weighted</i>
	<i>weighting</i>
	<i>weightings</i>
	<i>weights</i>
wild	
yellow	<i>yellow</i> s
yield	<i>yields</i>
young	

Name-like concepts	Merged Name-like concepts
American	
Anguilla	
Anguillicola	
Aquaculture's	Aquaculture
Eels	Eel's
	eel
European	
Fisheries	
Glass	
Japanese	
PCB	Pcbs
	Pcb's
Sargasso sea	

S1.4. Small corpus references

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S1.5. Main concepts (with a relevance $\geq 5\%$) revealed by the ACA.

Concept	Count	Relevance (%)
eel	89418	100
anguilla	18976	21
european	15159	17
migration	10353	12
glass	8794	10
growth	8182	9
silver	7714	9
diet	7316	8
japonica	7038	8
gene	6277	7
fisheries	5715	6
female	5683	6
exposure	5301	6
rostrata	5228	6
size	5196	6
population	5097	6
cell	4974	6
maturation	4973	6
length	4929	6
freshwater	4909	5
larvae	4847	5
river	4825	5
production	4647	5
temperature	4642	5
yellow	4628	5
body	4566	5
liver	4309	5
weight	4279	5
male	4217	5
environment	4209	5
catch	4200	5
restocking	4130	5
estuary	4128	5
sex ratio	4079	5

S1.7. Concepts associated with the “European”(a), “japonica”(b) and “rostrata”(c) concepts

(a)

Related Concept	Count	Likelihood (%)
anguilla	6780	36
nematode	329	33
sexual	403	33
stocks	1064	32
reproduction	721	30
sperm	410	29
continental	341	28
swimbladder	422	26
crassus	949	26
management	629	24
population	1216	24
spawning	867	24
lagoon	294	23
ocean	374	23
anthropogenic	107	22
virus	235	22
conservation	263	21
farm	383	21
maturation	1053	21
recruitment	708	21
parasite	549	20
inland	129	20
coast	562	20
leptocephali	168	20
catchment	170	20
cadmium	114	20
silver	1506	20
metamorphosis	167	19
health	121	18
migration	1867	18
wild	387	18
yield	124	18
larvae	856	18
infection	674	17
rostrata	913	17
dam	75	17
pesticides	103	17
disease	211	17
gene	1066	17
artificial	291	17

Supplementary material

eel	15098	17
quality	360	17
escapement	198	17
contaminants	465	16
protection	116	16
habitat	595	16
brackish	164	16
silvering	143	16
restocking	636	15
environment	626	15
juvenile	263	15
polluants	218	15
ecological	147	15
assessment	384	14
lake	326	14
hatching	190	14
freshwater	697	14
distribution	467	14
origin	175	14
brain	149	14
biomass	78	14
behavior	329	14
sea	335	14
adult	231	14
metabolites	78	14
aquaculture	448	14
fisheries	757	13
culture	289	13
river	630	13
catfish	61	13
mortality	337	13
long-term	93	13
glass	1096	12
marine	241	12
yellow	562	12
growth	991	12
hormone	398	12
immune	131	12
male	494	12
estuary	480	12
gonad	276	11
commercial	125	11
sex ratio	457	11
energy	188	11
japonica	776	11
female	619	11

Supplementary material

metal	215	11
density	232	10
age	380	10
survival	207	10
egg	283	10
toxic	128	10
metabolism	243	10
elver	302	10
fishermen	53	10
downstream	167	10
otolith	339	10
chemical	133	10
hepatic	78	10
young	54	9
oocyte	167	9
consumption	81	9
ovarian	175	9
temperature	417	9
pond	70	9
efficiency	93	9
stress	165	9
catch	358	9
fat	232	8
exposure	448	8
production	385	8
size	423	8
diet	584	8
tidal	78	8
upstream	143	8
body	353	8
release	147	8
movement	113	8
individual	303	8
thyroid	48	7
stream	93	7
blood	142	7
muscle	218	7
trout	192	7
gill	172	7
magnetic	42	7
length	333	7
bacterial	30	7
tissue	257	6
salinity	167	6
captured	89	6
plasma	166	6

damage	52	6
liver	237	6
organs	55	5
salmon	114	5
net	76	5
weight	193	5

(b)

Related Concept	Count	Likelihood (%)
artificial	638	37
leptocephali	265	32
ovarian	474	24
anguilla	3757	20
maturation	883	18
oocyte	308	17
hatching	203	15
spawning	516	14
egg	385	14
metamorphosis	121	14
larvae	663	14
culture	277	13
thyroid	80	12
immune	133	12
silvering	106	11
hormone	372	11
seawater	132	11
wild	235	11
ocean	178	11
otolith	374	11
aquaculture	338	10
nematode	97	10
ecological	96	10
salmon	203	9
production	415	9
habitat	335	9
gonad	215	9
reproduction	211	9
female	486	9
brain	91	8
disease	100	8
pond	60	8
sexual	93	8
eel	6778	8
coast	210	8
salinity	197	7

Supplementary material

elver	213	7
freshwater	348	7
male	293	7
rostrata	363	7
gene	433	7
sex ratio	276	7
diet	493	7
sperm	95	7
farm	117	7
juvenile	116	7
quality	140	6
commercial	70	6
continental	75	6
adult	100	6
swimbladder	96	6
estuary	246	6
magnetic	35	6
glass	502	6
growth	466	6
survival	113	6
cell	276	6
migration	568	5
young	30	5
conservation	64	5
sea	126	5
virus	56	5
crassus	192	5
european	776	5
temperature	235	5
intestinal	65	5
long-term	36	5
gill	118	5
marine	94	5
population	244	5
distribution	157	5
behavior	113	5
bacterial	21	5

(c)

Related Concept	Count	Likelihood (%)
anguilla	2681	14
stream	154	12
tidal	118	12
leptocephali	97	12
habitat	404	11

Supplementary material

elver	320	11
young	57	10
juvenile	176	10
estuary	389	9
ecological	94	9
metamorphosis	82	9
ocean	154	9
magnetic	56	9
otolith	325	9
origin	115	9
age	335	9
coast	255	9
movement	131	9
brackish	88	8
continental	103	8
captured	109	7
sex ratio	300	7
migration	739	7
spawning	253	7
recruitment	233	7
inland	42	7
growth	527	6
size	331	6
restocking	271	6
nematode	63	6
freshwater	310	6
river	291	6
european	913	6
population	306	6
anthropogenic	29	6
distribution	193	6
eel	5090	6
salinity	149	6
behavior	125	5
yellow	239	5
japonica	363	5
commercial	56	5
management	129	5
silver	386	5
upstream	92	5
pond	38	5
assessment	125	5
length	231	5
adult	77	5
parasite	121	5

Chapter 2 (S2)

S2.1. Script of the video (French and Japanese versions)

Note: the green part is the facultative part

Time code (in & out)	French Source	Translation
00:00:00 00:00:06	Dans la suite de ce questionnaire, vous allez devoir choisir entre plusieurs scénarios de conservation de l'anguille japonaise.	この一連のアンケートで、皆様にはニホンウナギの保護に関して複数のシナリオから選択していただきます。
00:00:07 00:00:15	En effet, l'anguille japonaise est classée comme espèce en danger d'extinction, sur la liste rouge de l'union internationale pour la conservation de la nature.	実は日本ウナギは絶滅危惧種として、国際自然保護連合のレッドリストに指定されています。
00:00:15 00:00:16	C'est pire que pour le panda !	これはパンダより危機的！
00:00:17 00:00:27	Sa population ne cesse de décroître depuis plusieurs décennies, et le nombre d'anguilles japonaises pêchées a chuté de plus de 97% ces 50 dernières années !	その数は数十年前から減少し続け、ニホンウナギの漁獲量はここ50年で97%以上もダウンしました！
00:00:28 00:00:35	Pour autant, la consommation d'anguilles au Japon reste élevée, puisqu'environ 50,000 tonnes y sont vendues chaque année.	それでも日本でのウナギ消費量は依然高く、年間約五万トンが販売されています。
00:00:36 00:00:41	Les anguilles consommées au Japon proviennent de trois sources : de la pêche, de l'aquaculture et de l'importation.	日本で消費されるウナギの供給源は漁獲、養殖、輸入の3種類。
00:00:42 00:00:48	En effet, une petite partie de ces anguilles sont des individus adultes capturées par des pêcheurs japonais.	こうしたウナギの一部は、日本の漁師が捕獲する成魚です。
00:00:49 00:00:58	Une partie plus importante provient de la pêche de jeunes anguilles, que l'on appelle les civelles, qui sont ensuite grossies dans des fermes avant d'être consommées adultes.	これより多いのは稚魚の段階での漁獲。シラスウナギと呼ばれる稚魚を養殖所で成長させ 成魚になってから消費します。

00:00:58 00:01:05	Attention, contrairement à d'autres espèces, l'anguille japonaise ne peut pas être reproduite artificiellement à large échelle.	ここで注意したいのは他の種と異なり、ニホンウナギを大量人工繁殖させるのは不可能だということ。
00:01:06 00:01:09	Ce sont donc uniquement des individus sauvages qui sont présents sur le marché.	すなわち市場に出回っているのは野性の個体のみ。
00:01:10 00:01:21	Enfin, la production japonaise ne suffisant pas à satisfaire la demande nationale, une majorité des anguilles consommées dans le pays sont importées, au stade adulte, afin d'approvisionner le marché.	最後に国内生産では需要を満たすのに不十分なので、日本で消費されるウナギの大半は市場供給のために輸入される成魚です。
00:01:22 00:01:33	Ces anguilles importées peuvent avoir été pêchées adultes ou au stade civelle puis grossies dans des fermes dans les pays exportateurs dont les principaux sont la Chine, la Corée du Sud et Taïwan.	こうした輸入ウナギは成魚で漁獲、または稚魚での漁獲後、輸出の養殖所で成長させたもの。主な輸出国は中国、韓国、そして台湾。
00:01:34 00:01:40	Cependant, il est très difficile pour le Japon de contrôler les anguilles qui proviennent de ces pays, notamment leur origine.	しかしこうした国々から輸入されるウナギの原産地などを日本で確認するのは非常に困難です。
00:01:40 --> 00:01:46	Une partie de ces anguilles importées proviendrait de la pêche illégale ou même d'importations illégales.	こうした輸入ウナギの一部は違法漁業、さらには密輸による可能性もあります。
00:01:47 --> 00:01:55	En effet, des anguilles européennes, qui sont en danger critique d'extinction, sont importées illégalement depuis les pays européens dans les pays qui fournissent le Japon.	実際、近絶滅種であるヨーロッパウナギは、欧州各国から日本への供給国に密輸されています。
00:01:58 --> 00:02:05	Dans tous les cas, qu'elles soient issues de la pêche, de l'aquaculture ou de l'importation, ces anguilles sont principalement consommées sous forme de kabayaki.	それが漁獲か、養殖か、輸入かに関わらず、こうしたウナギは主にかば焼きとして食されています。
00:02:06 --> 00:02:17	Ce plat emblématique de la cuisine japonaise s'achète au prix moyen de 1,280¥ les 100g d'après les données du Ministère des affaires intérieures et des communications.	日本料理を象徴するこの一品は、100gあたり1280円の平均価格で売買されていると総務省のデータが示しています。
00:02:17 --> 00:02:21	Vous avez maintenant toutes les informations clés en main pour répondre à la suite de ce questionnaire.	これで、この一連のアンケートに答えるのに必要な情報はすべて手にしたはずですよ。

S2.2. Questionnaire (English version)

Note: the Japanese version has been used for the survey

Welcome!

This survey is part of a research project conducted by researchers at INRAE (French National Research Institute for Agriculture, Food and Environment)

No particular knowledge is expected, the purpose of this questionnaire is to collect your opinion.

Thank you for your participation!

Your profile

1. Are you : **(one choice only)**
 - ☐ A woman
 - ☐ A man
 - ☐ Other
2. In what year are you born? **(four digits)** _ _ _ _
3. In which region do you live? **(scrolling banner)**
4. In which city/town/village? **(scrolling banner)**
5. Which of the following best represents your educational background? **(one choice only)**
 - ☐ Junior high school
 - ☐ High school
 - ☐ Vocational school / college
 - ☐ University
 - ☐ Graduate school
6. What is your job type? **(one choice only)**
 - ☐ Working for a company (general employee)
 - ☐ Company employee (manager)
 - ☐ Company management (executive manager)
 - ☐ Public employee, faculty member, non-profit organization employee
 - ☐ Temporary/contract employee
 - ☐ Self-employed (commercial and industrial services)
 - ☐ SOHO (small office/home office)
 - ☐ Agriculture, forestry, fishing
 - ☐ Professional occupation (lawyer, tax accountant, medical-related, etc)
 - ☐ Part-time job
 - ☐ Housewife/Househusband
 - ☐ Student

If you are looking for a job, please indicate your previous job.

7. How many people (including yourself) are living in your household and are aged : (fill all the table, put 0 if no one)

0-14years	
14-18years	
More than 18years	

8. What is your estimated total household income for 2022? (Include the income of all family members in your household) (One choice only)
- ☐ Less than 2,000,000 yen
 - ☐ 2,000,000-2,999,999 yen
 - ☐ 3,000,000-3,999,999 yen
 - ☐ 4,000,000-4,999,999 yen
 - ☐ 5,000,000-5,999,999 yen
 - ☐ 6,000,000-6,999,999 yen
 - ☐ 7,000,000-7,999,999 yen
 - ☐ 8,000,000-8,999,999 yen
 - ☐ 9,000,000-9,999,999 yen
 - ☐ 10,000,000 yen or more
9. Is (was) your professional activity or training related to the field of : (check yes or no, respondents working in these fields are not excluded)
- ☐ Fishery Yes ☐/ No ☐
 - ☐ Water management Yes ☐/ No ☐
 - ☐ Biodiversity conservation Yes ☐/ No ☐
 - ☐ Education or research Yes ☐/ No ☐

Your relationship to environment

10. Are you a member of an environmental association? (one choice only)
- ☐ Yes
 - ☐ No
11. What environmental actions do you favour:
- a. In terms of managing your waste? (several possible choices, spin the possibilities)
- ☐ You practice waste sorting (recycling)
 - ☐ You practice composting
 - ☐ You avoid buying single-use products or products with plastic packaging
 - ☐ You practice re-use (repair, second hand)
 - ☐ You practice zero waste
 - ☐ Other _____
 - ☐ You have not considered the question

b. About your diet? (several possible choices, spin the possibilities)

- ☐ You favor short circuits
- ☐ Your buy organic food
- ☐ You reduce your meat consumption
- ☐ You are vegetarian
- ☐ Other _____
- ☐ You have not considered the question

12. How much do you agree or disagree with the following statements? (mandatory answer for each statement)

a. We are approaching the limit of the number of people the earth can support

Totally agree	Agree	Rather agree	I don't know	Rather disagree	Disagree	Totally disagree
<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>

b. Humans have the right to modify the natural environment to suit their needs

Totally agree	Agree	Rather agree	I don't know	Rather disagree	Disagree	Totally disagree
<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>

c. When humans interfere with nature it often produces disastrous consequences

Totally agree	Agree	Rather agree	I don't know	Rather disagree	Disagree	Totally disagree
<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>

d. Human ingenuity will ensure that we do not make the earth unlivable

Totally agree	Agree	Rather agree	I don't know	Rather disagree	Disagree	Totally disagree
<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>

e. Humans are severely abusing the environment

Totally agree	Agree	Rather agree	I don't know	Rather disagree	Disagree	Totally disagree
<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>

f. The Earth has plenty of natural resources if we just learn how to develop them

Totally agree	Agree	Rather agree	I don't know	Rather disagree	Disagree	Totally disagree
<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>

g. Plants and animals have as much right as humans to exist

Totally agree	Agree	Rather agree	I don't know	Rather disagree	Disagree	Totally disagree
<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>

h. The balance of nature is strong enough to cope with the impacts of modern industrial nations

Totally agree	Agree	Rather agree	I don't know	Rather disagree	Disagree	Totally disagree
<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>

i. Despite our special abilities, humans are still subject to the laws of nature

Totally agree	Agree	Rather agree	I don't know	Rather disagree	Disagree	Totally disagree
<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>

j. The so-called “ecological crisis” facing humankind has been greatly exaggerated

Totally agree	Agree	Rather agree	I don't know	Rather disagree	Disagree	Totally disagree
<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>

k. The Earth is like a spaceship with very limited room and resources

Totally agree	Agree	Rather agree	I don't know	Rather disagree	Disagree	Totally disagree
<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>

l. Humans were meant to rule over the rest of nature

Totally agree	Agree	Rather agree	I don't know	Rather disagree	Disagree	Totally disagree
<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>

m. The balance of nature is very delicate and easily upset

Totally agree	Agree	Rather agree	I don't know	Rather disagree	Disagree	Totally disagree
<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>

n. Humans will eventually learn enough about how nature works to be able to control it

Totally agree	Agree	Rather agree	I don't know	Rather disagree	Disagree	Totally disagree
<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>

- o. If things continue on their present course, we will soon experience a major ecological catastrophe

Totally agree	Agree	Rather agree	I don't know	Rather disagree	Disagree	Totally disagree
<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>

13. In your opinion, what is an endangered wild species? (several possible choices, spin the possibilities)

- ☐ A species whose population is in strong decline
- ☐ A species whose habitats are threatened
- ☐ A poached species
- ☐ A species with a low number of breeders
- ☐ A highly commercialised species
- ☐ I don't know

14. Which of these species do you think are threatened with extinction? (several possible choices, spin the possibilities)

- ☐ The Atlantic bluefin tuna (*Thunnus thynnus*)
- ☐ The gorilla (*Gorilla gorilla*)
- ☐ The griffon vulture (*Gyps fulvus*)
- ☐ The scallop shell (*Pecten maximus*)
- ☐ The Melibeus butterfly (*Coenonympha hero*)
- ☐ No one
- ☐ I don't know

Note: pictures where added to illustrate each proposition but they have been removed in order to avoid copyrights issues

15. From your perspective, the conservation of endangered animal species should be achieved through: (two possible choices, spin the possibilities, add instruction)

- ☐ The establishment of protected areas
- ☐ The implementation of awareness campaigns for the general public
- ☐ The ban on trade (in species and by-products)
- ☐ The livestock or aquaculture development
- ☐ The ex-situ conservation (zoos, reserves, etc.)
- ☐ Other _____
- ☐ I don't know

16. In your opinion, what are the main threats to the survival of marine and freshwater fish? (two possible choices, spin the possibilities, add instructions)

- ☐ Illegal fishery
- ☐ Not strict enough Regulations
- ☐ Water pollution
- ☐ Overfishing
- ☐ Climate change
- ☐ Obstacles and barriers (dams, dikes, mills, etc.)

- ☐ Other_____
- ☐ I don't know

17. Have you ever heard of the eel? (one choice only, if answer « no » = questions 17/18 and go to the video directly)

- ☐ Yes
- ☐ No

18. In your opinion, what is the status of this species? (several possible choices, spin the possibilities)

- ☐ It is an invasive species
- ☐ It is a nuisance species
- ☐ It is an endangered species
- ☐ It is a fished species
- ☐ It is a species that is not fished
- ☐ It is a species that can be eaten
- ☐ It is a species that can't be eaten
- ☐ I don't know

19. In your opinion, most of the eels sold in the market are? (one choice only)

- ☐ Wild
- ☐ Artificially reproduced
- ☐ Both
- ☐ I don't know

20. Have you ever eat some eel? (one choice only)

- ☐ Yes
- ☐ No
- ☐ I don't know

21. If yes,

a. For which reason(s)? (several possible choices, spin the possibilities)

- ☐ For the taste
- ☐ For health benefits
- ☐ For cultural reasons
- ☐ Because it is a luxury food
- ☐ Because you had the opportunity
- ☐ Just out of curiosity
- ☐ Other_____

b. Where did you eat eel? (several possible choices, spin the possibilities)

- ☐ At the restaurant
- ☐ At your place
- ☐ At your friends/family's place
- ☐ Somewhere else_____

- c. At what stage(s) of their growth? (several possible choices)
- ☐ Juvenile (glass eel)
 - ☐ Adult
 - ☐ I don't know
- d. How often? (several possible choices)
- ☐ Regularly
 - ☐ Occasionally
 - ☐ Only for special events
 - ☐ You only ate once
- e. Do you care for the origin of the eel you eat? (one choice only)
- ☐ Yes
 - ☐ No
- f. If yes: (one choice only)
- ☐ The information is quite easy to be found
 - ☐ The information is not easy to be found
- g. If no: (one choice only)
- ☐ You would if the information was easier to be found
 - ☐ You wouldn't even if the information was easier to be found
- h. Do you prefer to eat: (one choice only)
- ☐ Farmed eels
 - ☐ Wild eels
 - ☐ Both
 - ☐ You don't know
22. If not: for which reason(s)? (several possible choices, spin the possibilities)
- ☐ It doesn't tempt you
 - ☐ You did not have the opportunity
 - ☐ It is too expensive
 - ☐ It's bad for your health
 - ☐ For environmental purpose
 - ☐ Other _____
23. Have you ever caught eels? (one choice only)
- ☐ Yes, I have
 - ☐ No
 - ☐ I don't know
24. If yes, it was: (several possible choices)
- ☐ For professional purpose

- ☐ For recreational purpose

25. If yes, at which stage of growth? (**several possible choices**)

- ☐ Juveniles (glass eels)
- ☐ Adults
- ☐ I don't know

26. Has anyone you know ever caught eels? (**one choice only**)

- ☐ Yes, a relative
- ☐ Yes, a friend
- ☐ Yes, an acquaintance
- ☐ No
- ☐ I don't know

27. If yes, it was: (**several possible choices**)

- ☐ For professional purpose
- ☐ For recreational purpose

28. If yes, at which stage of growth? (**several possible choices**)

- ☐ Juveniles (glass eels)
- ☐ Adults
- ☐ I don't know

How to adapt eel consumption to improve its conservation?

This video will give you the essential information you need to know before continuing the questionnaire: enjoy!

Remember to turn on the sound to hear the explanations 😊

Video file « with information » or « without information » (depending on the questionnaire version)

29. How much has the number of Japanese eels caught in the last 50 years dropped? (**control question**)

- ☐ 13%
- ☐ 48%
- ☐ 74%
- ☐ 97%

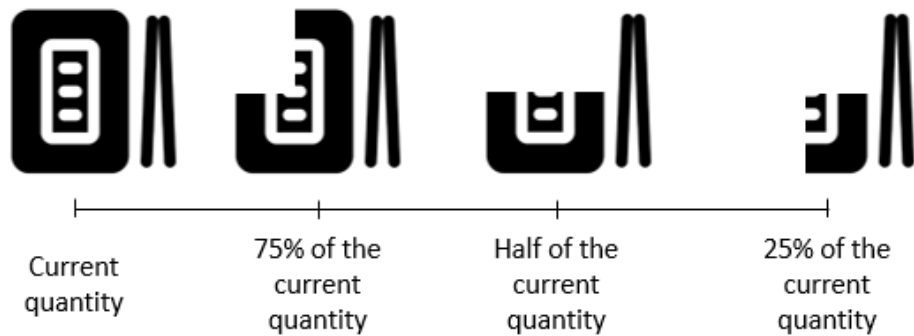
30. From which countries are eels mainly imported into Japan? (**control question**)

- ☐ Thailand, China and Philippines
- ☐ China, South Korea and Taiwan
- ☐ Indonesia, South Korea and Taiwan
- ☐ Philippines, Taiwan and Indonesia

You will now have to choose between several scenarios. Each one contains 6 criteria which can vary to different levels:

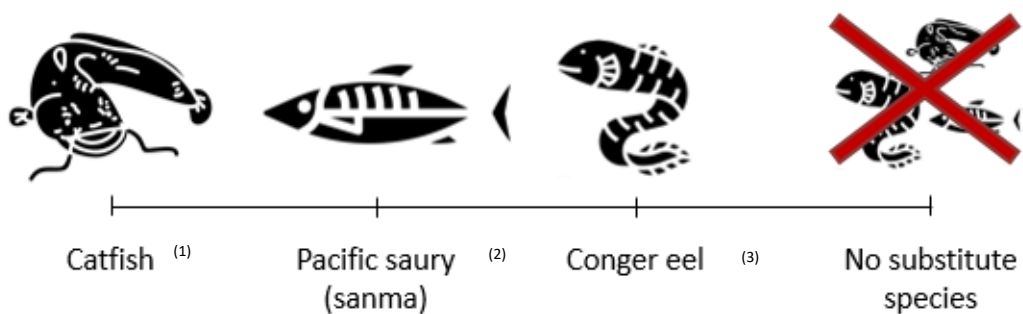
- **Criterion 1: the global quantity of eels consumed in Japan by 2030, compared to the current quantity (around 50,000 tons).**

You may choose between four different levels of consumed quantity of eel:



- **Criterion 2: the substitution of part of the eel consumption by other species.**

You may choose between three different substitute species or choose not to substitute eel:



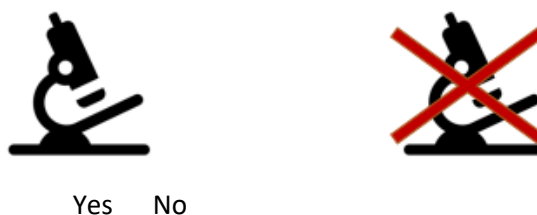
⁽¹⁾ kindai catfish is a product developed by Kinki university. It is said it has does not have the fishy smell typical of catfish, achieved through a special feeding regimen

⁽²⁾ *Cololabis saira* has a similar long shape as eel and is also sometimes eaten with kabayaki sauce

⁽³⁾ *Conger myriaster* is similar in shape but different in texture

- **Criterion 3: the development of research about eel reproduction**

It would allow the eel aquaculture by making artificial reproduction. You may choose to encourage the development of this research or not:



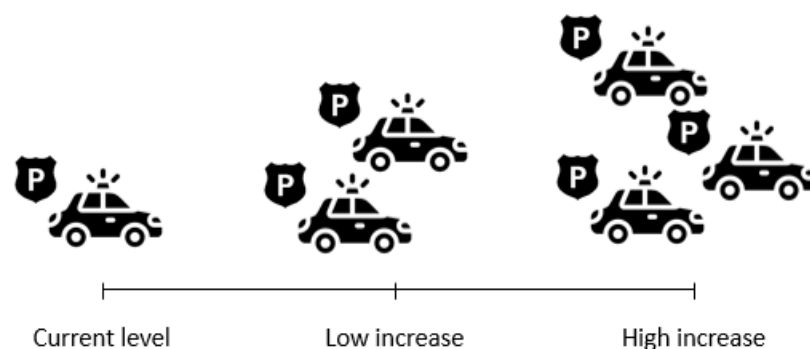
- **Criterion 4: the public awareness**

You may choose between setting up a label to follow the product from the beginning to the end (you would be able to know its origin, if it is wild or farmed, etc.), or setting up a largescale public awareness campaign or to not develop the public access to information:



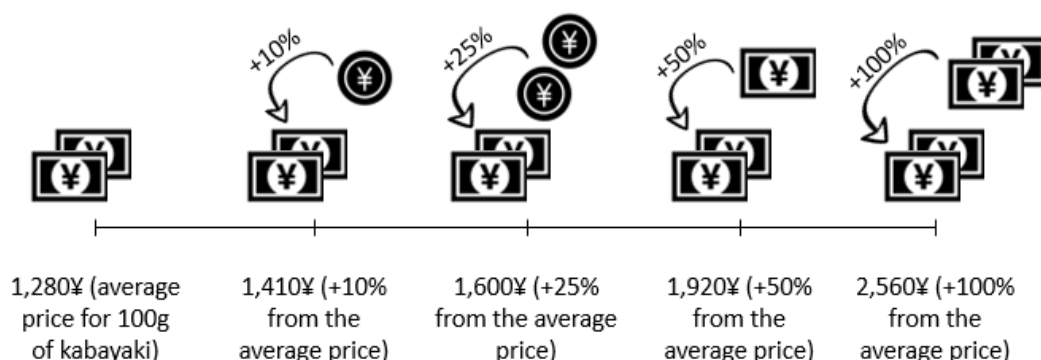
- **Criterion 5: the fight against illegal eel trade by controlling imports**

You may choose between 3 different levels including the current level, a low increase of this current level or a high increase. This level cover all the resources: staff, budget, equipment, etc.



- **Criterion 6: the average price for 100g of kabayaki**

The reference price is the average price of 100g of kabayaki in 2021: ¥1,280 (source: Ministry of Internal Affairs and Communications). Depending on the scenario, you may choose between 5 levels of prices from this average price to twice (+0%; +10%; +25%; +50%; +100%):





















Six pages will follow one another with 3 options each time (in columns).

Please, indicate which option you are most satisfied with.









Attention: Once you have validated a choice, you will not be able to go back

(Layout: each choice question is on one screen. All choice questions are mandatory)








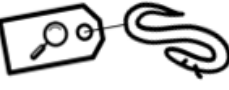





31. First choice set:

	Option 1	Option 2	Option 3
Global quantity of eels consumed in Japan by 2030, compared to the current quantity (around 50,000 tons)	 25% of the current quantity	 Current quantity	 Current quantity
Partial substitution of eel consumption by other species	 No substitute species	 Sanma	 No substitute species
Development of research about artificial eel reproduction	 Yes	 No	 Yes
Public awareness	 Set up a largescale public awareness campaign	 No development of the access to information	 No development of the access to information
Fight against illegal eel trade by controlling imports	 Low increase	 High increase	 Current level
Average price for 100g of kabayaki compared to the current one	 2,560¥ (+100% from the average price)	 1,410¥ (+10% from the average price)	 1,280¥ (current average price for 100g of kabayaki)
Your choice:	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>



32. Second choice set:

	Option 1	Option 2	Option 3
Global quantity of eels consumed in Japan by 2030, compared to the current quantity (around 50,000 tons)	 Half of the current quantity	 Half of the current quantity	 Current quantity
Partial substitution of eel consumption by other species	 Catfish	 Sanma	 No substitute species
Development of research about artificial eel reproduction	 Yes	 No	 Yes
Public awareness	 Set up a largescale public awareness campaign	 Set up a label (traceability, origine, farmed or wild)	 No development of the access to information
Fight against illegal eel trade by controlling imports	 High increase	 Low increase	 Current level
Average price for 100g of kabayaki compared to the current one	 1,600¥ (+25% from the average price)	 1,920¥ (+50% from the average price)	 1,280¥ (current average price for 100g of kabayaki)
Your choice:	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>

33. Third choice set:

	Option 1	Option 2	Option 3
Global quantity of eels consumed in Japan by 2030, compared to the current quantity (around 50,000 tons)	 75% of the current quantity	 Half of the current quantity	 Current quantity
Partial substitution of eel consumption by other species	 Conger eel	 Catfish	 No substitute species
Development of research about artificial eel reproduction	 Yes	 No	 Yes
Public awareness	 Set up a label (traceability, origine, farmed or wild)	 Set up a largescale public awareness campaign	 No development of the access to information
Fight against illegal eel trade by controlling imports	 Low increase	 Current level	 Current level
Average price for 100g of kabayaki compared to the current one	 1,410¥ (+10% from the average price)	 2,560¥ (+100% from the average price)	 1,280¥ (current average price for 100g of kabayaki)
Your choice:	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>

















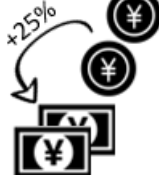

34. Fourth choice set:

	Option 1	Option 2	Option 3
Global quantity of eels consumed in Japan by 2030, compared to the current quantity (around 50,000 tons)	 Current quantity	 25% of the current quantity	 Current quantity
Partial substitution of eel consumption by other species	 Conger eel	 No substitute species	 No substitute species
Development of research about artificial eel reproduction	 No	 Yes	 Yes
Public awareness	 No development of the access to information	 Set up a label (traceability, origine, farmed or wild)	 No development of the access to information
Fight against illegal eel trade by controlling imports	 Low increase	 Current level	 Current level
Average price for 100g of kabayaki compared to the current one	 2,560¥ (+100% from the average price)	 1,410¥ (+10% from the average price)	 1,280¥ (current average price for 100g of kabayaki)
Your choice:	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>

35. Fifth choice set:

	Option 1	Option 2	Option 3
Global quantity of eels consumed in Japan by 2030, compared to the current quantity (around 50,000 tons)	 Half of the current quantity	 75% of the current quantity	 Current quantity
Partial substitution of eel consumption by other species	 No substitute species	 Catfish	 No substitute species
Development of research about artificial eel reproduction	 No	 Yes	 Yes
Public awareness	 No development of the access to information	 Set up a label (traceability, origine, farmed or wild)	 No development of the access to information
Fight against illegal eel trade by controlling imports	 High increase	 Low increase	 Current level
Average price for 100g of kabayaki compared to the current one	 1,410¥ (+10% from the average price)	 2,560¥ (+100% from the average price)	 1,280¥ (current average price for 100g of kabayaki)
Your choice:	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>

36. Sixth choice set:

	Option 1	Option 2	Option 3
Global quantity of eels consumed in Japan by 2030, compared to the current quantity (around 50,000 tons)	 75% of the current quantity	 75% of the current quantity	 Current quantity
Partial substitution of eel consumption by other species	 No substitute species	 Conger eel	 No substitute species
Development of research about artificial eel reproduction	 No	 Yes	 Yes
Public awareness	 No development of the access to information	 Set up a largescale public awareness campaign	 No development of the access to information
Fight against illegal eel trade by controlling imports	 Current level	 High increase	 Current level
Average price for 100g of kabayaki compared to the current one	 2,560¥ (+100% from the average price)	 1,600¥ (+25% from the average price)	 1,280¥ (current average price for 100g of kabayaki)
Your choice:	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>

37. What would you say about the choices you have just made? (one choice only)

Very difficult	Difficult	Not easy or difficult	Easy	Very easy
<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>

38. Was your choices: (one choice only)

Very certain	Certain	Not certain or uncertain	Uncertain	Very uncertain
<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>

39. For what reason(s) have you chosen the option 3, at least once? (only for respondents who chose this option at least once) (several possible choices, only respondents who selected option 3 at least once can answer this question).

- ☐ You think that the status quo does not endanger the Japanese eel
- ☐ You don't want to pay more for kabayaki
- ☐ You don't really feel concerned about the decline of the Japanese eel population
- ☐ You don't think you can afford to pay more for kabayaki
- ☐ Other (please specify) _____

S2.3. Probabilities a posterieuri (% by characteristic for each classes)

	Class 1		Class 2		Class 3	
	Mean	Standard error	Mean	Standard error	Mean	Standard error
< 40 years old	29% +	0.0004	31% +	0.0002	24% -	0.0003
[40-60[years old	50% +	0.0004	46% -	0.0003	46% -	0.0003
≥ 60 years old	21% -	0.0003	23% -	0.0005	30% +	0.0005
Higher education	62% -	0.0003	69% +	0.0004	65% +	0.0003
Income < 4,000,000 yen	49% +	0.0004	41% -	0.0003	38% -	0.0005
4,000,000 yen ≤ Income < 8,000,000 yen	35% -	0.0004	38% +	0.0004	48% +	0.0007
3,000,000 yen ≤ Income < 4,000,000 yen	26%	0.0003	25%	0.0001	23% -	0.0003
5,000,000 yen ≤ Income < 8,000,000 yen	25% -	0.0004	27%	0.0003	35% +	0.0007
Income ≥ 8,000,000 yen	16% -	0.0003	20% +	0.0002	14% -	0.0002
Pro-environmental behaviors	35% +	0.0003	26% -	0.0002	47% +	0.0005
Living in rural area	27% -	0.0006	37%	0.0005	28%	0.0004
Living in urban area	73% +	0.0006	63%	0.0005	72% +	0.0004
Knowledge about the eel status (endangered species)	63% -	0.0005	76% +	0.0003	69% +	0.0004
Knowledge about what is an endangered species	34% -	0.0005	37% -	0.0003	49% +	0.0003
Living in Chubu region	15% +	0.0003	15% +	0.0002	17% +	0.0003
Living in Chugoku region	11% -	0.0002	13%	0.0003	8% -	0.0001
Living in Hokkaido region	7% -	0.0002	9% -	0.0002	8% -	0.0002
Living in Kansai region	18% +	0.0003	14% +	0.0002	15% +	0.0002
Living in Kanto region	22% +	0.0009	23% +	0.001	25% +	0.0009
Living in Kyushu region	10% -	0.0004	8% -	0.0003	71% -	0.0002
Living in Shikoku region	7% -	0.0003	8% -	0.0003	7% -	0.0003
Living in Tohoku region	10% -	0.0002	11% -	0.0003	12% -	0.0003

+ means that the proportion is significantly higher than the average

- means that the proportion is significantly lower than the average

Note that a proportion is significantly different than the average when the 95% confidence intervals are not overlapping.

S2.4. Summary of the answers to the NEP and factorial analysis

(a) Number of answers, average scores per questions and associated NEP dimensions

Questions	Agree	Disagree	don't know	Rather agree	Rather disagree	Totally agree	Totally disagree	ScaleDim	mean	sd
Q1	24	1	30	27	4	12	3	Reality to limits of growth	4.945772	1.302393
Q2	16	8	32	18	13	6	7	Anti-anthropocentrism	3.816176	1.546946
Q3	29	1	24	29	2	13	2	Fragility of nature's balance	5.188419	1.191187
Q4	15	2	45	24	7	4	2	Anti-exceptionalism	3.517463	1.166722
Q5	31	1	20	30	3	14	1	Possibility of an eco-crisis	5.231618	1.197065
Q6	19	4	35	24	10	6	3	Reality to limits of growth	3.476103	1.319090
Q7	30	1	21	26	3	19	1	Anti-anthropocentrism	5.373162	1.205055
Q8	10	12	38	13	18	4	5	Fragility of nature's balance	4.118566	1.412816
Q9	26	1	33	23	3	13	1	Anti-exceptionalism	5.030331	1.249102
Q10	11	8	43	17	12	4	3	Possibility of an eco-crisis	3.877757	1.322351
Q11	29	1	28	25	3	12	1	Reality to limits of growth	5.120404	1.198445
Q12	8	13	40	13	15	3	8	Anti-anthropocentrism	4.286765	1.433766
Q13	32	1	25	25	2	14	1	Fragility of nature's balance	5.234375	1.194604
Q14	8	11	39	17	14	4	6	Anti-exceptionalism	4.120404	1.413311
Q15	28	1	28	24	3	15	1	Possibility of an eco-crisis	5.171875	1.213562

(b) Alpha test

Item	Obs	Sign	item-test correlation	item-rest correlation	average interitem covariance	alpha
NEP_1	19584	+	0.6038	0.5189	.4333219	0.8299
NEP_2	19584	-	0.5465	0.4344	.4339467	0.8359
NEP_3	19584	+	0.6315	0.5583	.4343462	0.8281
NEP_4	19584	-	0.6504	0.5815	.4329297	0.8270
NEP_5	19584	+	0.6082	0.5313	.437388	0.8296
NEP_6	19584	-	0.5581	0.4656	.4397925	0.8331
NEP_7	19584	+	0.5727	0.4907	.4421212	0.8318
NEP_8	19584	-	0.4630	0.3515	.4523831	0.8404
NEP_9	19584	+	0.5734	0.4882	.4401884	0.8318
NEP_10	19584	-	0.5232	0.4261	.4451581	0.8354
NEP_11	19584	+	0.5887	0.5092	.440111	0.8308
NEP_12	19584	-	0.4670	0.3542	.451188	0.8404
NEP_13	19584	+	0.5752	0.4943	.4421944	0.8316
NEP_14	19584	-	0.4849	0.3758	.4486797	0.8389
NEP_15	19584	+	0.6153	0.5383	.4355987	0.8291
Test scale					.4406232	0.8423

(c) Number of factors (dimensions)

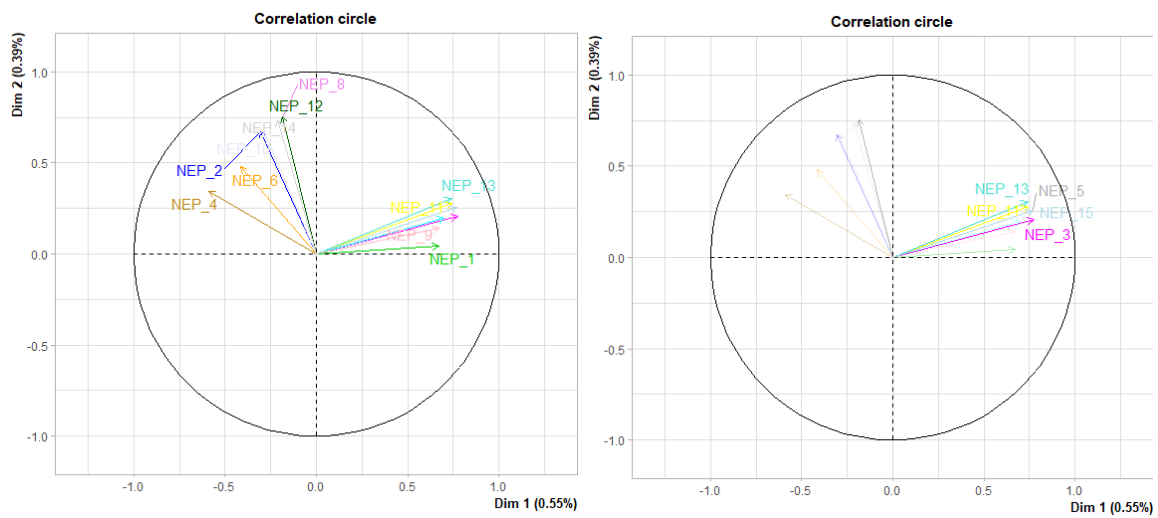
Factor analysis/correlation	Number of obs	=	19,584
Method: principal factors	Retained factors	=	2
Rotation: (unrotated)	Number of params	=	29

Factor	Eigenvalue	Difference	Proportion	Cumulative
Factor1	4.57321	1.78253	0.6552	0.6552
Factor2	2.79068	2.51673	0.3998	1.0551
Factor3	0.27395	0.07712	0.0393	1.0943
Factor4	0.19683	0.12207	0.0282	1.1225
Factor5	0.07476	0.02804	0.0107	1.1332
Factor6	0.04672	0.07117	0.0067	1.1399
Factor7	-0.02445	0.03284	-0.0035	1.1364
Factor8	-0.05729	0.01224	-0.0082	1.1282
Factor9	-0.06952	0.01733	-0.0100	1.1182
Factor10	-0.08685	0.01155	-0.0124	1.1058
Factor11	-0.09840	0.01510	-0.0141	1.0917
Factor12	-0.11350	0.03016	-0.0163	1.0754
Factor13	-0.14366	0.04260	-0.0206	1.0549
Factor14	-0.18626	0.01040	-0.0267	1.0282
Factor15	-0.19666	.	-0.0282	1.0000

LR test: independent vs. saturated: $\chi^2(105) = 1.3e+05$ Prob> $\chi^2 = 0.0000$

(d) Factorial analysis

Variable	Factor1	Factor2	Uniqueness
NEP_1	0.6236	0.0232	0.6105
NEP_2	-0.2768	0.6147	0.5456
NEP_3	0.7473	0.1774	0.4101
NEP_4	-0.5370	0.3192	0.6098
NEP_5	0.7424	0.2247	0.3983
NEP_6	-0.3706	0.4264	0.6808
NEP_7	0.6570	0.1621	0.5420
NEP_8	-0.1625	0.6939	0.4921
NEP_9	0.6278	0.1111	0.5935
NEP_10	-0.2614	0.6187	0.5488
NEP_11	0.7196	0.2426	0.4233
NEP_12	-0.1663	0.7044	0.4761
NEP_13	0.7164	0.2683	0.4147
NEP_14	-0.1936	0.6832	0.4958
NEP_15	0.7453	0.2234	0.3946



Factorial analysis. On the right: selection of the 5 modalities (necessarily active) that contributed most to the construction of the layout

S2.5. Scores and proportions of high (5, 6, 7) and low (1, 2, 3) scores a posterieuri for NEP's items

+ means that the proportion is significantly higher than the average

- means that the proportion is significantly lower than the average

Note that a proportion is significantly different than the average when the 95% confidence intervals are not overlapping.

(a) Class 1

NEP dimension	NEP question number	Score		% high score answers (5, 6, 7)		% low score answers (1, 2, 3)	
		Mean	Standard error	Mean	Standard error	Mean	Standard error
Limits of growth	1	4.9 -	0.001	62%	0.0005	8%	0.0001
	6	3.5	0.0008	19% +	0.0004	49%	0.0004
	11	5.1 -	0.0008	65% -	0.0004	5%	0.0001
Anti-anthropocentrism	2	3.7 -	0.001	24% -	0.0004	45% +	0.0005
	7	5.3 -	0.0006	75%	0.0003	4%	0.0001
	12	4.2 -	0.001	32% -	0.0006	27% +	0.0002
Fragility of balance	3	5.2 -	0.0007	70% -	0.0003	4%	0.0001
	8	4 -	0.001	30% -	0.0004	32% +	0.0003
	13	5.2 -	0.0007	68% -	0.0003	4%	0.0001
Rejection of exemptionalism	4	3.6 +	0.0005	12%	0.0002	42% -	0.0005
	9	5	0.0009	61%	0.0005	6%	0.0001
	14	4 -	0.0007	29% -	0.0003	32% +	0.0003
Ecocrisis	5	5.2 -	0.0007	72% -	0.0003	6%	0.00009
	10	3.8 -	0.0009	20% -	0.0003	38% +	0.00004
	15	5.1 -	0.0008	65% -	0.0004	6% +	0.0001

(b) Class 2

<i>NEP dimension</i>	NEP question number	<i>Score</i>		<i>% high score answers (5, 6, 7)</i>		<i>% low score answers (1, 2, 3)</i>	
		Mean	Standard error	Mean	Standard error	Mean	Standard error
Limits of growth	1	4.8 ⁻	0.0006	57% ⁻	0.0002	11% ⁺	0.0001
	6	3.4 ⁻	0.0006	14% ⁻	0.0001	50% ⁺	0.0003
	11	5.1	0.0005	68% ⁺	0.0003	3% ⁻	0.00009
Anti-anthropocentrism	2	4.1 ⁺	0.001	35% ⁺	0.0006	31% ⁻	0.0005
	7	5.3 ⁻	0.0007	74% ⁻	0.0003	5% ⁺	0.00009
	12	4.3 ⁺	0.0007	41% ⁺	0.0003	24%	0.0002
Fragility of balance	3	5.2 ⁺	0.0005	77% ⁺	0.0003	3% ⁻	0.00008
	8	4.3 ⁺	0.0009	42% ⁺	0.0002	22% ⁻	0.0003
	13	5.3 ⁺	0.0007	74% ⁺	0.0003	4% ⁻	0.0002
Rejection of exemptionalism	4	3.5	0.0008	10% ⁻	0.0002	41% ⁻	0.0003
	9	5	0.0007	62% ⁺	0.0003	6% ⁺	0.0001
	14	4.2 ⁺	0.0006	33% ⁺	0.0003	27% ⁻	0.0002
Ecocrisis	5	5.2	0.0006	76% ⁺	0.0002	5% ⁻	0.0001
	10	4 ⁺	0.001	27% ⁺	0.0004	30% ⁻	0.0002
	15	5.2	0.0007	71% ⁺	0.0003	5%	0.00009

(c) Class 3

NEP dimension	NEP question number	Score		% high score answers (5, 6, 7)		% low score answers (1, 2, 3)	
		Mean	Standard error	Mean	Standard error	Mean	Standard error
Limits of growth	1	5.2 ⁺	0.001	68% ⁺	0.0004	5% ⁻	0.0001
	6	3.4 ⁻	0.001	22% ⁺	0.0005	55% ⁺	0.0004
	11	5.4 ⁺	0.001	74% ⁺	0.0003	4% ⁻	0.00007
Anti-anthropocentrism	2	3.8 ⁻	0.002	29% ⁺	0.0005	44% ⁺	0.0004
	7	5.6 ⁺	0.0008	68% ⁻	0.0004	3% ⁻	0.00006
	12	4.5 ⁺	0.001	43% ⁺	0.0004	22% ⁻	0.0002
Fragility of balance	3	5.4 ⁺	0.0008	79% ⁺	0.0003	4% ⁻	0.00008
	8	4.1 ⁻	0.001	39% ⁺	0.0005	31% ⁺	0.0004
	13	5.4 ⁺	0.0009	78% ⁺	0.0003	5% ⁺	0.00008
Rejection of exemptionalism	4	3.4 ⁻	0.0007	14% ⁺	0.0002	49% ⁺	0.0004
	9	5.2 ⁺	0.0008	65% ⁺	0.0003	6% ⁻	0.0001
	14	4.2 ⁺	0.0009	40% ⁺	0.0003	31% ⁺	0.0003
Ecocrisis	5	5.5 ⁺	0.001	82% ⁺	0.0003	5% ⁻	0.00008
	10	4 ⁺	0.002	32% ⁺	0.0005	34% ⁺	0.0004
	15	5.5 ⁺	0.001	77% ⁺	0.0004	3% ⁻	0.00008

Chapter 3 (S3)

S3.1: Survey and data

(a) Survey (in French)

The following questionnaire was distributed to professional eel fishermen in the BU of interest (LCVS), by the PO Estuaires, the CORPEM, the AAPPED44 and the AAPPBLB. In addition to this, a series of interviews were conducted with representatives of various organizations (ARA, COREPEM, AAPPED44, PO Estuaires)

Enquête auprès des pêcheurs professionnels d'anguille de l'unité de gestion Loire, côtiers vendéens et Sèvre niortaise.

Le repeuplement a été mis en place dans le cadre du Plan de Gestion de l'Anguille français depuis 2011 comme mesure de conservation de l'anguille européenne. Son efficacité intéresse des chercheurs de l'INRAE (Institut national de recherche pour l'agriculture, l'alimentation et l'environnement) et cette enquête est organisée dans le cadre d'une thèse de doctorat, afin de récolter des données **anonymes**. Elles permettront, d'une part de décrire la pêcherie d'anguille dans l'unité de gestion Loire, côtiers vendéens et Sèvre niortaise et d'autre part, d'approvisionner un modèle qualitatif permettant d'expliciter les effets du repeuplement (comme politique de gestion) sur cette pêcherie.

L'enquête est à destination de tout pêcheur professionnel possédant une licence lui permettant de pêcher l'un ou plusieurs des trois stades de l'anguille européenne (civelle, anguille jaune, anguille argentée).

Le temps de réponse est estimé à 15 minutes en moyenne (un peu moins si vous ne ciblez que l'anguille jaune et/ou argentée, un peu plus si vous ciblez la civelle).



Activité de pêche

1) Quelle est votre année de naissance ?

2) Depuis quelle année êtes-vous :

Pêcheur professionnel ?

Patron pêcheur ?

Supplementary material

*3) Combien avez-vous de salariés ? (sans vous inclure)

*4) Quelles sont les organisations de producteurs ou/et associations de pêcheurs professionnels auxquelles vous adhérez ?

📌 Cochez la ou les réponses

☐ OP Estuaires

☐ COREPEM

☐ Aucune

☐ AAPED 44

☐ CDPMEM17

☐ Autre :

*5) La pêche est-elle votre seule activité professionnelle ?

☐ Oui

☒ Non

Quelles sont vos autres activités professionnelles ?

Pratique de la pêche à l'anguille

6) Si vous êtes propriétaire d'un ou plusieurs bateau(x), veuillez compléter le tableau ci-dessous :

	Bateau 1	Bateau 2	Bateau 3
Taille (en mètres)	<input type="text"/>	<input type="text"/>	<input type="text"/>
Puissance (en kW)	<input type="text"/>	<input type="text"/>	<input type="text"/>
Année d'acquisition	<input type="text"/>	<input type="text"/>	<input type="text"/>
Année de construction	<input type="text"/>	<input type="text"/>	<input type="text"/>

*7) Quel(s) stade(s) de l'anguille ciblez-vous ?

📌 Cochez la ou les réponses

☒ Civelles

☒ Anguille jaune

☒ Anguille argentée

8)a. Quel(s) engin(s) utilisez-vous pour cibler la civelle ?

	Précision sur le type	Dimension cadre	Nombre
Tamis à civelles	<input type="text"/>	<input type="text"/>	<input type="text"/>
Autre	<input type="text"/>	<input type="text"/>	<input type="text"/>

8)b. Quel(s) engin(s) utilisez-vous pour cibler l'anguille jaune ? (Ne remplissez que les lignes qui vous concernent.)

* à choisir selon le type d'engin

	Précision sur le type	Maille (mm) ou nbr d'ha-meçons /ligne *	Long. (m) ou nbr *
Verveux	<input type="text"/>	<input type="text"/>	<input type="text"/>
Nasse	<input type="text"/>	<input type="text"/>	<input type="text"/>

8)c. Quels engins utilisez-vous pour cibler l'anguille argentée ? (Ne remplissez que les lignes qui vous concernent.)

* à choisir selon le type d'engin

	Précision sur le type	Maille (mm) ou nbr d'ha-meçons /ligne *	Long. (m) ou nbr *
Verveux	<input type="text"/>	<input type="text"/>	<input type="text"/>
Guideau	<input type="text"/>	<input type="text"/>	<input type="text"/>

Carrelet	<input type="text"/>	<input type="text"/>	<input type="text"/>
Epervier	<input type="text"/>	<input type="text"/>	<input type="text"/>
Filet	<input type="text"/>	<input type="text"/>	<input type="text"/>
Ligne de fond	<input type="text"/>	<input type="text"/>	<input type="text"/>
Bourgne	<input type="text"/>	<input type="text"/>	<input type="text"/>
Autre	<input type="text"/>	<input type="text"/>	<input type="text"/>

Autre	<input type="text"/>	<input type="text"/>	<input type="text"/>
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Dernière période de pêche à l'anguille

Les questions qui vont suivre concernent la dernière période de pêche, soit la pêche effectuée **depuis le 1er Octobre 2020 jusqu'à fin Novembre 2021** (cette dernière période comprend donc la dernière saison de pêche à la civelle, à l'anguille jaune et à l'anguille argentée).

Certaines questions porteront sur le chiffre d'affaire. Nous tenons à préciser que nous ne cherchons pas à savoir votre chiffre d'affaire précis ! Seuls des intervalles de grandeur vous seront demandés.

***9) Quelle(s) licence(s) de pêche possédiez-vous lors de cette dernière période de pêche ?**

Rappel : la dernière période de pêche correspond à la période entre le 1er Octobre 2020 et la fin de Novembre 2021.

Cochez la ou les réponses

- ☐ Licence CMEA sans droit de pêche en zone fluviale
- ☐ Licence CMEA avec droit de pêche dans les lots 14 et 15
- ☐ Licence CMEA avec droit de pêche dans les lots 13,14 et 15
- ☐ Licence fluviale Civelle
- ☐ Licence fluviale Anguille Jaune
- ☐ Licence fluviale Grande Pêche

***Quel(s) droit(s) de pêche spécifique(s) aviez-vous ?**

Cochez la ou les réponses

- ☐ Civelle
- ☐ Anguille jaune
- ☐ Anguille argentée

10)a. Pour chaque mois, à quelle intensité êtes-vous sortis pêcher la civelle ?

	Jamais	Rarement	Parfois	Souvent	Tous les jours
Décembre 2020	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Janvier 2021	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Février 2021	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Mars 2021	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Avril 2021	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>

Quelle est la durée moyenne d'une sortie de pêche à la civelle dans de bonnes conditions ? (en heure)

Remarque : par bonnes conditions, on entend ressource abondante, bonnes conditions hydrologiques et climatiques, pas d'avarie, marché favorable, quotas disponibles, ...

Quelle est la durée moyenne d'une sortie de pêche à la civelle dans de mauvaises conditions ? (en heure)

Remarque : par mauvaises conditions, on entend ressource peu abondante, mauvaises conditions hydrologiques et climatiques, marché peu favorable, avarie, quotas presque épuisés, ...

Supplementary material

10)b. Pour chaque mois, à quelle intensité êtes-vous sortis pêcher l'anguille jaune ?

	Jamais	Rarement	Parfois	Souvent	Tous les jours
Avril 2021	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Mai 2021	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Juin 2021	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Juillet 2021	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Août 2021	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Septembre 2021	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Octobre 2021	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Novembre 2021	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>

10)c. Pour chaque mois, à quelle intensité êtes-vous sortis pêcher l'anguille argentée ?

	Jamais	Rarement	Parfois	Souvent	Tous les jours
Octobre 2020	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Novembre 2020	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Décembre 2020	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Janvier 2021	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Février 2021	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>

11) Quelles sont les autres espèces que vous avez majoritairement ciblées lors de cette dernière période de pêche ?

(On ne parle pas ici des captures accessoires mais d'espèces cibles)

	De décembre 2020 à avril 2021	D'avril 2021 à novembre 2021	D'octobre 2020 à février 2021 (pour les pêcheurs qui ciblent l'anguille argentée uniquement)
Espèce 1	<input type="text"/>	<input type="text"/>	<input type="text"/>
Espèce 2	<input type="text"/>	<input type="text"/>	<input type="text"/>
Espèce 3	<input type="text"/>	<input type="text"/>	<input type="text"/>

★12) Que représente le chiffre d'affaire de la pêche à l'anguille (tous stades confondus) par rapport à votre chiffre d'affaire total annuel ?

Remarque : cette question concerne toujours la dernière période de pêche

☐ Plus de 75%
 ☐ Entre 50 et 75%
 ☐ Entre 25 et 50%
 ☐ Moins de 25%

13) Comment cette part de revenue a-t-elle globalement évolué ces trois dernières années ?

☐ ↗
 ☐ →
 ☐ ↘

Please note: questions 12 and 13 appear only if the fisherman is targeting several stages

<p>*14)a. Que représente le chiffre d'affaire de la pêche à la civelle par rapport à votre chiffre d'affaire total annuel ?</p> <p>Remarque : cette question concerne toujours la dernière période de pêche</p> <p> <input type="radio"/> Plus de 75% <input type="radio"/> Entre 25 et 50% <input type="radio"/> Entre 50 et 75% <input type="radio"/> Moins de 25% </p>	<p>Comment cette part de revenue a-t-elle globalement évolué ces trois dernières années ?</p> <p> <input type="radio"/> ↗ <input type="radio"/> → <input type="radio"/> ↘ </p>
<p>*14)b. Que représente le chiffre d'affaire de la pêche à l'anguille jaune par rapport à votre chiffre d'affaire total annuel ?</p> <p>Remarque : cette question concerne toujours la dernière période de pêche</p> <p> <input type="radio"/> Plus de 75% <input type="radio"/> Entre 25 et 50% <input type="radio"/> Entre 50 et 75% <input type="radio"/> Moins de 25% </p>	<p>Comment cette part de revenue a-t-elle globalement évolué ces trois dernières années ?</p> <p> <input type="radio"/> ↗ <input type="radio"/> → <input type="radio"/> ↘ </p>
<p>*14)c. Que représente le chiffre d'affaire de la pêche à l'anguille argentée par rapport à votre chiffre d'affaire total annuel ?</p> <p>Remarque : cette question concerne toujours la dernière période de pêche</p> <p> <input type="radio"/> Plus de 75% <input type="radio"/> Entre 25 et 50% <input type="radio"/> Entre 50 et 75% <input type="radio"/> Moins de 25% </p>	<p>Comment cette part de revenue a-t-elle globalement évolué ces trois dernières années ?</p> <p> <input type="radio"/> ↗ <input type="radio"/> → <input type="radio"/> ↘ </p>
<p>*15) Dans quelle fourchette se situe votre chiffre d'affaire total de la pêche (pour toutes espèces confondues) ?</p> <p>Remarque : cette question concerne toujours la dernière période de pêche</p> <p> <input type="radio"/> Moins de 50 000 € <input type="radio"/> Entre 200 000 et 250 000 € <input type="radio"/> Entre 50 000 et 100 000 € <input type="radio"/> Entre 250 000 et 300 000 € <input type="radio"/> Entre 100 000 et 150 000 € <input type="radio"/> Plus de 300 000 € <input type="radio"/> Entre 150 000 et 200 000 € </p>	<p>Comment a globalement évolué ce chiffre d'affaire ces 3 dernières années ?</p> <p> <input type="radio"/> ↗ <input type="radio"/> → <input type="radio"/> ↘ </p>

16) A quelle fréquence avez-vous été contrôlé lors de vos activités de pêche à la civelle ?

Remarque : cette question concerne toujours la dernière période de pêche

☐ Plus d'une fois par mois ☐ Une fois par mois
☐ Moins d'une fois par mois ☐ Jamais

Please note: question 16 appear only if the fisherman is targeting elvers

Commercialisation

*17)a. Comment commercialisez-vous les civelles pêchées ?

📌 Cochez la ou les réponses

- ☐ En vente directe au consommateur
- ☐ En vente à un intermédiaire (mareyeur, poissonnier, coopérative, ...)
- ☐ En passant par les centres de stockage de l'OP Estuaires
- ☐ Autre :

*17)b. Comment commercialisez-vous les anguilles adultes (soient jaunes et argentées) pêchées ?

📌 Cochez la ou les réponses

- ☐ En vente directe au consommateur
- ☐ En vente à un intermédiaire (mareyeur, poissonnier, coopérative, ...)
- ☐ Autre :

*18) Quelle quantité de civelles allouées au repeuplement avez-vous pêché lors de la dernière saison de pêche ?

- ☐ Moins de 30kg
- ☐ Entre 30 et 40 kg
- ☐ Entre 40 et 50 kg
- ☐ Entre 50 et 60 kg
- ☐ Entre 60 et 70kg
- ☐ Entre 70 et 80 kg
- ☐ Entre 80 et 90 kg
- ☐ Entre 90 et 100 kg
- ☐ Plus de 100 kg

*19) Quelle quantité de civelles allouées à la consommation avez-vous pêché lors de la dernière saison de pêche ?

- ☐ Moins de 30kg
- ☐ Entre 30 et 40 kg
- ☐ Entre 40 et 50 kg
- ☐ Entre 50 et 60 kg
- ☐ Entre 60 et 70kg
- ☐ Entre 70 et 80 kg
- ☐ Entre 80 et 90 kg
- ☐ Entre 90 et 100 kg
- ☐ Plus de 100 kg

*20) A quel prix en moyenne avez-vous vendu un kilogramme de civelles pour la consommation lors de la dernière saison de pêche ?

- ☐ Moins de 150 € le kg
- ☐ De 150 à 200 € le kg
- ☐ De 200 à 250 € le kg
- ☐ De 250 à 300 € le kg
- ☐ De 300 à 350 € le kg
- ☐ De 350 à 400 € le kg
- ☐ De 400 à 450 € le kg
- ☐ De 450 à 500 € le kg
- ☐ De 500 à 550 € le kg
- ☐ De 550 à 600 € le kg
- ☐ Plus de 600 € le kg

*21) A quel prix en moyenne avez-vous vendu un kilogramme de civelles pour le repeuplement lors de la dernière saison de pêche ?

- ☐ Moins de 50 € le kg
- ☐ De 50 à 100 € le kg
- ☐ De 100 à 150 € le kg
- ☐ De 150 à 200 € le kg
- ☐ De 200 à 250 € le kg
- ☐ De 250 à 300 € le kg
- ☐ De 300 à 350 € le kg
- ☐ Plus de 350 € le kg

Pour finir, nous allons vous demander de vous prononcer sur les mesures de conservation de l'anguille européenne proposées dans le règlement européen No 1100/2007, et dont le repeuplement fait parti.

Pensez-vous que de telles mesures soient efficaces, c'est-à-dire qu'elles fonctionnent bien, dans le but de restaurer le stock d'anguilles européennes ?

	<u>Vous pensez que cette mesure n'est pas du tout efficace pour restaurer le stock d'anguilles</u>	<u>Vous pensez que cette mesure n'est pas vraiment efficace pour restaurer le stock d'anguilles</u>	<u>Vous pensez que cette mesure est plutôt efficace pour restaurer le stock d'anguilles</u>	<u>Vous pensez que cette mesure est très efficace pour restaurer le stock d'anguilles</u>	<u>Vous pensez que c'est la mesure principale qui permettra de restaurer le stock d'anguilles</u>
La réduction de l'activité de pêche commerciale	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
La limitation de la pêche récréative	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Les mesures de repeuplement	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Les mesures structurelles visant à permettre le franchissement des rivières et à améliorer les habitats dans les cours d'eau, conjointement avec d'autres mesures de protection de l'environnement	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Le transport des anguilles argentées des eaux intérieures vers des eaux d'où elles puissent migrer librement vers la mer des Sargasses	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>

La lutte contre les prédateurs	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
L'arrêt temporaire des turbines des centrales hydroélectriques	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Les mesures en faveur de l'aquaculture	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>

Si vous souhaitez ajouter quelque chose, n'hésitez pas à le faire dans l'espace ci-dessous :

Remarks:

- Questions 18 to 21 appear only if the angler is targeting glass eels.
- a. appear only if the angler is targeting glass eels
- b. appear only if the angler is targeting yellow eel
- The c. appear only if the angler is targeting silver eel
- The * indicates questions requiring an answer

(b) General analysis

This questionnaire was intended for eel fishermen, irrespective of the stage they were targeting in the eels' lifecycle. We were able to gather 41 responses, including 31 targeting European glass eel. As there were around 200 fishermen targeting glass eel in this area (reference), our sample represents around 15% of the overall population. Four of the 31

respondents targeting glass eel stopped answering at the part concerning the commercialization of their catch. The fishing season of interest was the year 2020-2021.

Table with age of fishermen and details about their boats:

	Average	SD	Min	Max
Fisherman's age	45	11.4	23	63
Age at which they started professional fishing	23	11.6	18	23
Boat size	8.05	1.94	5	15 *
Boat power	69.03	44.8	10	302
Year of purchase (boat)	2010	9.48	1988	2021
Year built (boat)	1992	16.29	1936	2020

*Note that for glass eel fishing, boat size is limited to 12m

According to the survey results, the majority of glass eel fishermen in this area work alone onboard. Only a few of them have employees. Fishing is their only professional activity, except for a few of them who also work on mussel farms.

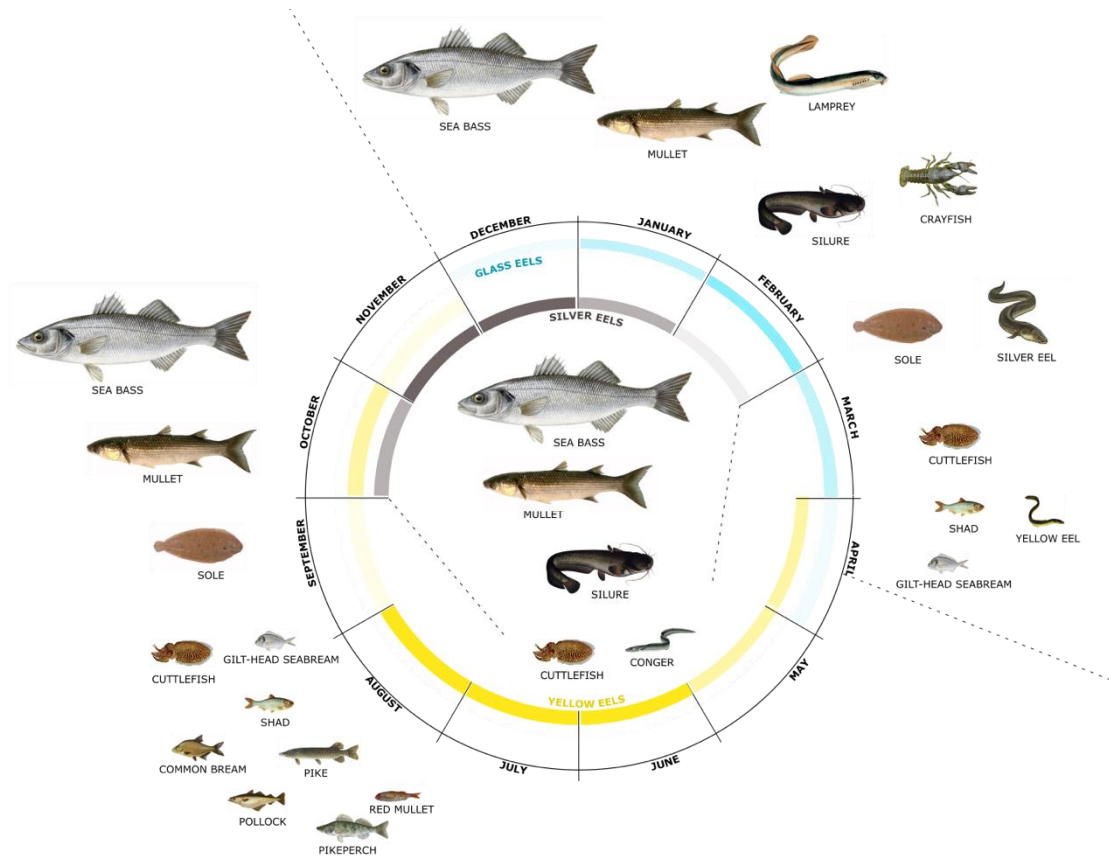
A majority of eel fishermen have one boat (28), some of them have two (11) and only two have three boats.

Glass eel fishermen mainly use round screens with a 120cm diameter. Yellow and silver eel fishermen mainly use fyke nets and eel traps (*verveux*, *guideau* and *bosselles*).

Thirteen glass eel fishermen have a maritime license while six have an inland license. Eleven of them have a mixed situation with either a license that allows them to catch glass eel at a precise distance from the saline limit, or both this license and an inland license.

(c) Annual fishing schedule

The bigger the picture of the fish, the more important that species is in terms of catch and effort; and the more intense the color in the circle, the more the species is targeted.



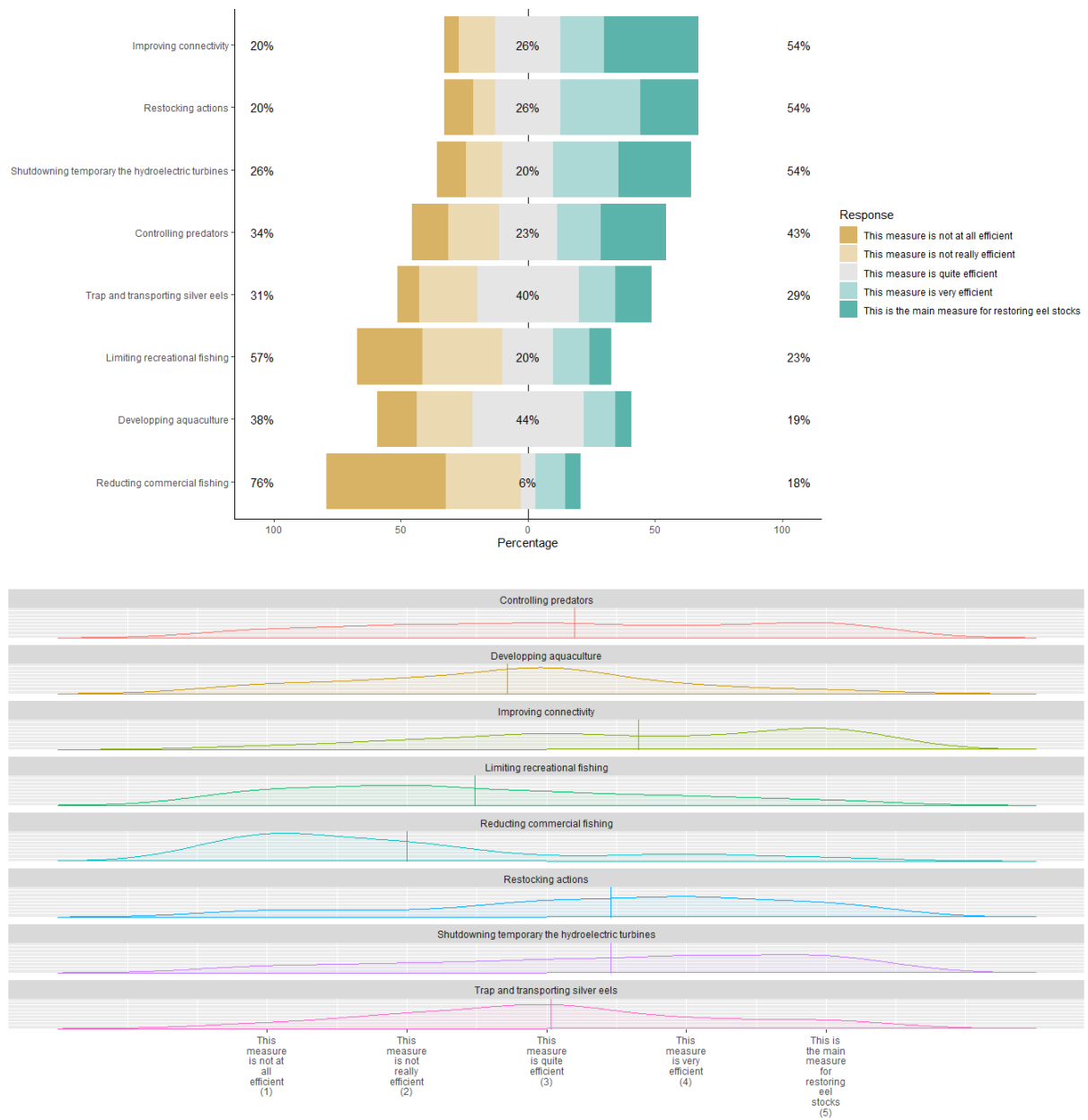
When it comes to commercialization, 15 fishermen sell the glass eels they catch to middlemen, while 13 of them use the storage facilities provided by the "Estuaires" PO.

(d) Economic results

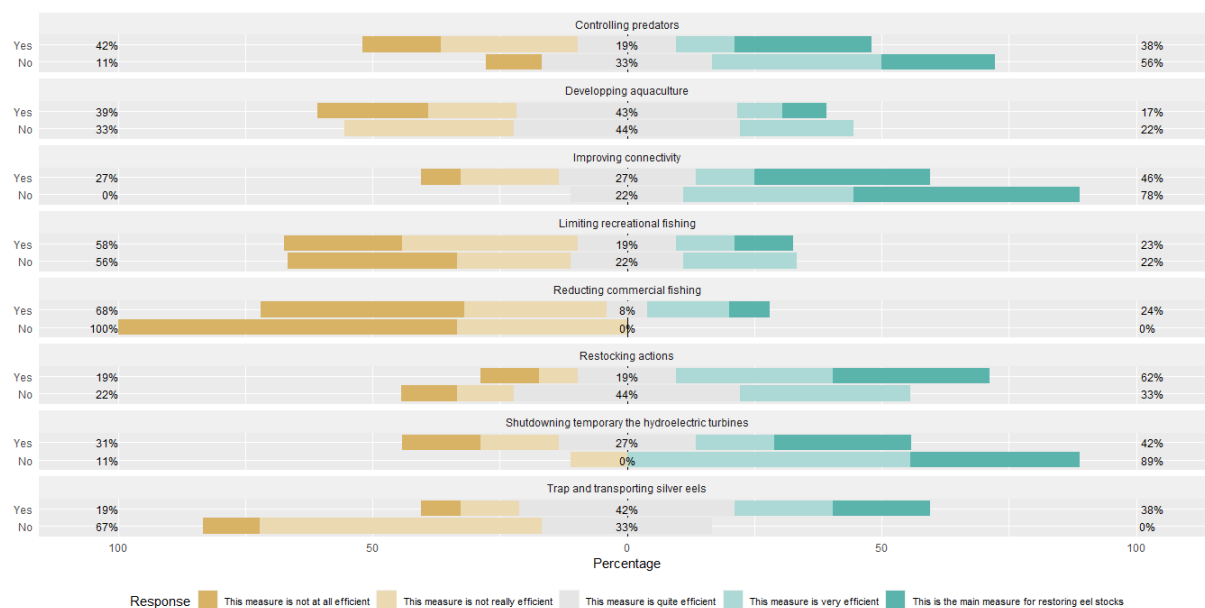
For fishermen targeting glass eels, this species accounts for between 30 and 60% of their revenue (which is between €70,000 and €100,000 per annum). The evolution of this revenue and the part represented by glass eel has remained quite stable over the last three years.

Approximately 60% of the income from glass eel fishing comes from sales for consumption, while about 40% comes from sales for restocking.

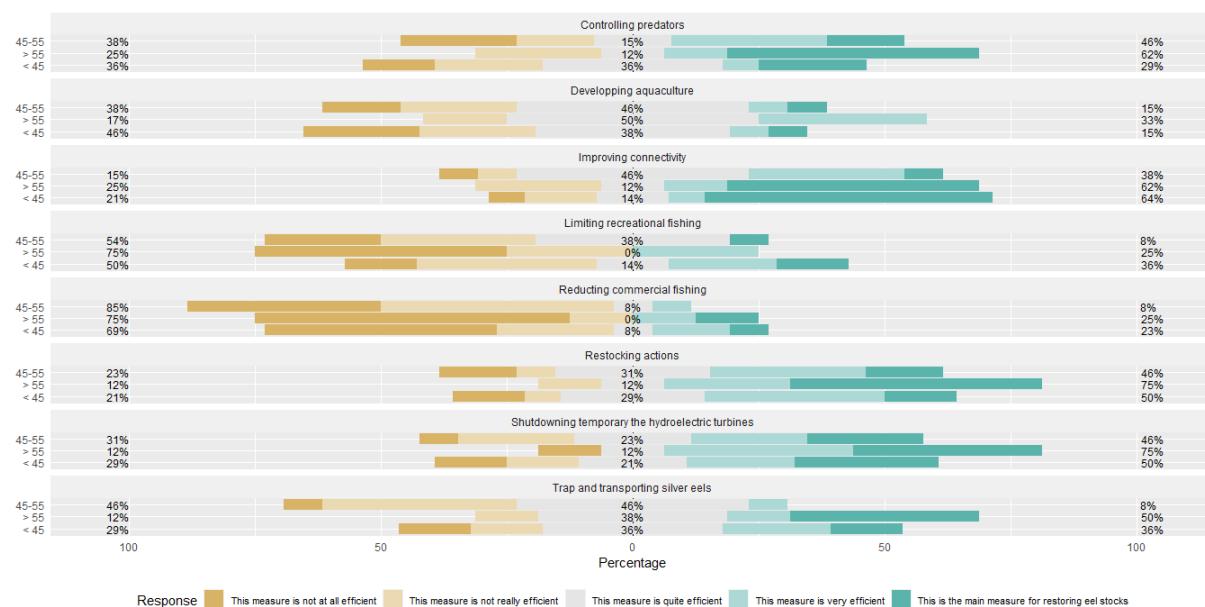
(e) Fishermen's preferences



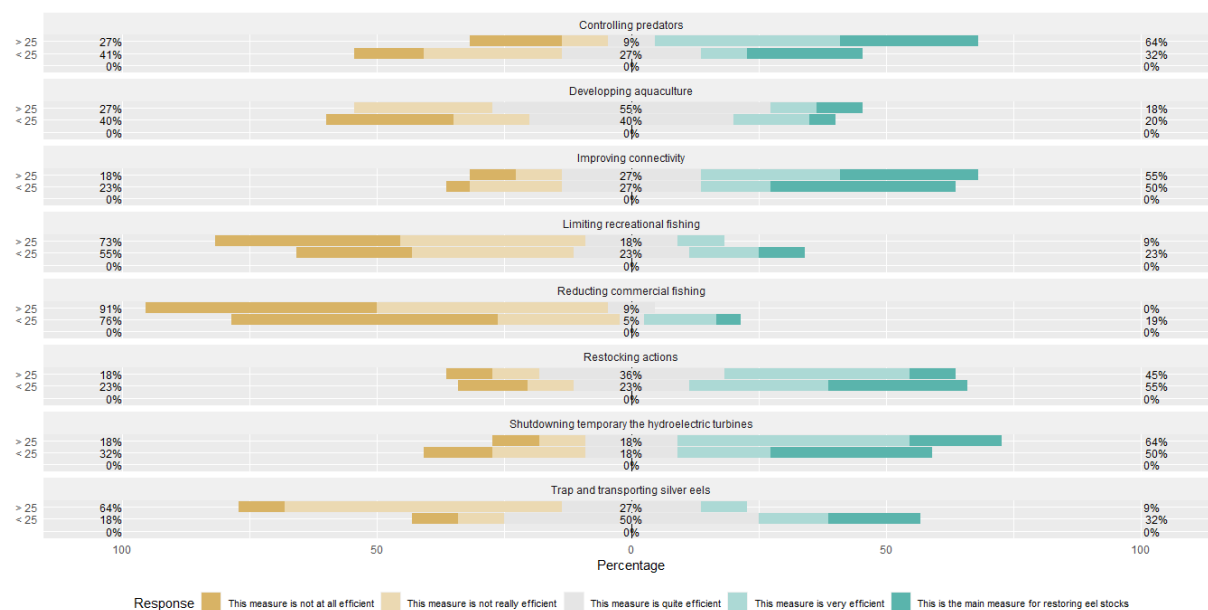
Group: catching glass eel (Yes) or not (No)



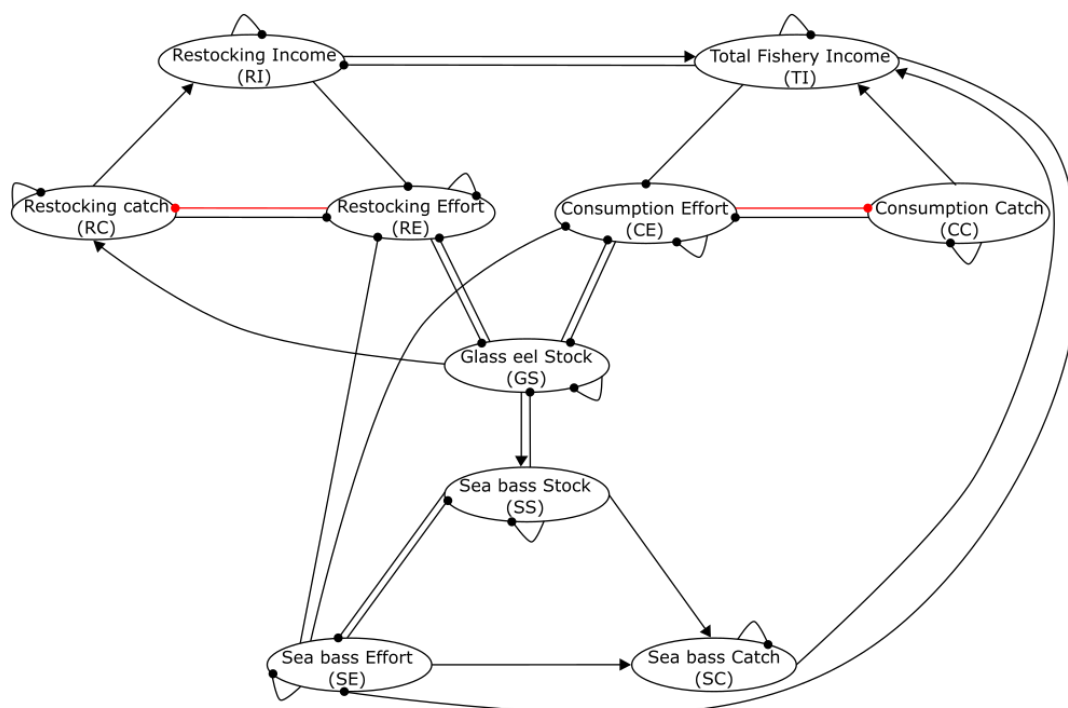
Age groups



Age at which they became professional fishermen:



S3.2: Alternative model



S3.3: Simulation input and outputs for model 1

Community matrix

	GS	CE	CC	RE	RC	SS	SE	SC	RI	TI
GS	-1	-1	0	-1	1	1	0	0	0	0
CE	-1	-1	1	0	0	0	0	0	0	0
CC	0	-1	-1	0	0	0	0	0	0	1
RE	-1	0	0	-1	1	0	0	0	0	0
RC	0	0	0	-1	-1	0	0	0	1	0
SS	-1	0	0	0	0	-1	-1	1	0	0
SE	0	-1	0	-1	0	-1	-1	1	0	0
SC	0	0	0	0	0	0	0	-1	0	1
RI	0	0	0	-1	0	0	0	0	-1	1
TI	0	-1	0	0	0	0	-1	0	-1	-1

Matrix determinant (must be non-zero) = 26

Number of accepted moves = 18,445

Number of loops = 100,000

Percentage of “+”

	GS	CE	CC	RE	RC	SS	SE	SC	RI	TI
GS	75.58688	49.72621	49.72621	42.46679	75.80916	96.85552	7.24316	55.88506	59.38737	64.98238
CE	9.36297	97.69585	97.69585	84.35890	53.41827	10.95148	59.01870	20.51504	23.00895	76.95853
CC	48.52263	13.40201	91.78097	70.68040	84.94443	83.93603	3.58363	32.09000	35.71157	88.99431
RE	12.05747	53.10382	53.10382	97.04527	90.78341	20.19517	53.02792	21.85958	86.63052	77.53863
RC	59.19219	51.46652	51.46652	15.77663	94.22608	93.61887	2.97642	40.05964	85.40526	82.87341
SS	0.46083	93.21225	93.21225	99.14882	61.22526	67.44375	23.76254	38.19463	39.06208	73.88452
SE	98.23800	2.43969	2.43969	7.00461	39.58796	62.62402	90.98943	93.65682	31.43941	53.36406
SC	10.96774	54.83329	54.82787	95.89049	84.28300	50.18704	9.67200	88.16481	21.29574	97.64164
RI	36.45432	53.83573	53.83573	46.44077	32.31770	82.72703	1.69694	23.89265	94.79534	93.43996
TI	10.96774	54.83329	54.83329	95.89049	84.28300	50.18704	9.67200	13.32068	21.29574	97.64164

Percentage of “-”

	GS	CE	CC	RE	RC	SS	SE	SC	RI	TI
GS	24.41312	50.27379	50.27379	57.53321	24.19084	3.14448	92.75684	44.11494	40.61263	35.01762
CE	90.63703	2.30415	2.30415	15.64110	46.58173	89.04852	40.98130	79.48496	76.99105	23.04147
CC	51.47737	86.59799	8.21903	29.31960	15.05557	16.06397	96.41637	67.91000	64.28300	11.00569
RE	87.94253	46.89618	46.89618	2.95473	9.21659	79.80483	46.97208	78.14042	13.36948	22.46137
RC	40.80781	48.53348	48.53348	84.22337	5.77392	6.38113	97.02358	59.94036	14.59474	17.12659
SS	99.53917	6.78775	6.78775	0.85118	38.77474	32.55625	76.23746	61.80537	60.93792	26.11548
SE	1.76200	97.56031	97.56031	92.99539	60.41204	37.37598	9.01057	6.34318	68.56059	46.63594
SC	89.03226	45.16671	45.16671	4.10951	15.71700	49.80754	90.32800	11.83519	78.70426	2.35836
RI	63.54568	46.16427	46.16427	53.55923	67.68230	17.27297	98.30306	76.10735	5.20466	6.56004
TI	89.03226	45.16671	45.16671	4.10951	15.71700	49.80754	90.32800	86.67932	78.70426	2.35836

Percentage of “0”

	GS	CE	CC	RE	RC	SS	SE	SC	RI	TI
GS	0	0	0.00000	0	0	0.00000	0	0	0.00000	0
CE	0	0	0.00000	0	0	0.00000	0	0	0.00000	0
CC	0	0	0.00000	0	0	0.00000	0	0	0.00542	0
RE	0	0	0.00000	0	0	0.00000	0	0	0.00000	0
RC	0	0	0.00000	0	0	0.00000	0	0	0.00000	0
SS	0	0	0.00000	0	0	0.00000	0	0	0.00000	0
SE	0	0	0.00000	0	0	0.00000	0	0	0.00000	0
SC	0	0	0.00542	0	0	0.00542	0	0	0.00000	0
RI	0	0	0.00000	0	0	0.00000	0	0	0.00000	0
TI	0	0	0.00000	0	0	0.00542	0	0	0.00000	0

S3.4: Simulation input and outputs for model 2

Community matrix

	GS	CE	CC	RE	RC	SS	SE	SC	RI	TI
GS	-1	-1	0	-1	1	1	0	0	0	0
CE	-1	-1	1	0	0	0	0	0	0	0
CC	0	-1	-1	0	0	0	0	0	0	1
RE	-1	0	0	-1	1	0	0	0	0	0
RC	0	0	0	-1	-1	0	0	0	1	0
SS	-1	0	0	0	0	-1	-1	1	0	0
SE	0	0	0	-1	0	-1	-1	1	0	0
SC	0	0	0	0	0	0	0	-1	0	1
RI	0	0	0	-1	0	0	0	0	-1	1
TI	0	-1	0	0	0	0	-1	0	-1	-1

Matrix determinant (must be non-zero) = 20

Number of accepted moves = 21,113

Number of loops = 100,000

Percentage of “+”

	GS	CE	CC	RE	RC	SS	SE	SC	RI	TI
GS	79.10292	20.01137	20.01137	38.66812	73.18240	97.77862	8.50187	60.55984	67.74499	54.34093
CE	9.19339	98.44645	98.44645	83.91986	54.50670	12.18207	58.12059	20.91602	23.25581	78.36404
CC	54.82404	5.46583	84.00985	66.21039	83.66409	88.87889	4.52802	36.79250	43.53716	83.37991
RE	13.61247	55.69081	55.68607	96.25823	89.69355	23.40264	53.56889	21.58859	83.75409	81.38114
RC	65.79832	19.59930	19.59930	14.29451	93.14640	97.53233	3.90281	45.65434	88.87415	75.02487
SS	1.18884	87.06958	87.06958	98.33752	61.29399	68.50282	24.47307	41.02212	43.47085	72.08355
SE	96.67503	8.72922	8.72922	9.35443	39.74802	50.59916	91.84862	91.57865	22.31327	61.83394
SC	16.80481	32.94653	32.94653	93.09430	85.43078	61.16137	9.74281	90.52243	25.68560	96.85502
RI	45.84853	22.76796	22.76796	40.49638	33.04125	92.16123	1.80931	29.38474	96.69398	89.19149
TI	16.80481	32.94653	32.94653	93.09430	85.43078	61.16137	9.74281	16.18434	25.68560	96.85502

Percentage of “-”

	GS	CE	CC	RE	RC	SS	SE	SC	RI	TI
GS	20.89708	79.98863	79.98863	61.33188	26.81760	2.22138	91.49813	39.44016	32.25501	45.65907
CE	90.80661	1.55355	1.55355	16.08014	45.49330	87.81793	41.87941	79.08398	76.74419	21.63596
CC	45.17596	94.53417	15.99015	33.78961	16.33591	11.12111	95.47198	63.20750	56.46284	16.62009
RE	86.38753	44.30919	44.30919	3.74177	10.30645	76.59736	46.43111	78.41141	16.24591	18.61886
RC	34.20168	80.40070	80.39596	85.70549	6.85360	2.46767	96.09719	54.34566	11.12585	24.97513
SS	98.81116	12.93042	12.93042	1.66248	38.70601	31.49718	75.52693	58.97788	56.52915	27.91645
SE	3.32497	91.27078	91.27078	90.64557	60.25198	49.40084	8.15138	8.42135	77.68673	38.16606
SC	83.19519	67.04874	67.05347	6.90570	14.56922	38.83863	90.25719	9.47757	74.31440	3.14498
RI	54.15147	77.23204	77.23204	59.50362	66.95875	7.83877	98.19069	70.61526	3.30602	10.80851
TI	83.19519	67.04874	67.05347	6.90570	14.56449	38.83863	90.25719	83.81566	74.31440	3.14498

Percentage of “0”

	GS	CE	CC	RE	RC	SS	SE	SC	RI	TI
GS	0	0.00000	0.00000	0	0.00000	0	0	0	0	0
CE	0	0.00000	0.00000	0	0.00000	0	0	0	0	0
CC	0	0.00000	0.00000	0	0.00000	0	0	0	0	0
RE	0	0.00000	0.00474	0	0.00000	0	0	0	0	0
RC	0	0.00000	0.00474	0	0.00000	0	0	0	0	0
SS	0	0.00000	0.00000	0	0.00000	0	0	0	0	0
SE	0	0.00000	0.00000	0	0.00000	0	0	0	0	0
SC	0	0.00474	0.00000	0	0.00000	0	0	0	0	0
RI	0	0.00000	0.00000	0	0.00000	0	0	0	0	0
TI	0	0.00474	0.00000	0	0.00474	0	0	0	0	0

Predictions table

	GS	CE	CC	RE	RC	SS	SE	SC	RI	TI
GS	+	-	-	?-	?+	+	-	?+	?+	0*
CE	-	+	+	+	0*	-	0*	-	-	+
CC	0*	-	+	?+	+	+	-	?-	0*	+
RE	-	0*	0*	+	+	-	0*	-	+	+
RC	?+	-	-	-	+	+	-	0*	+	+
SS	-	+	+	+	?+	?+	-	0*	0*	?+
SE	+	-	-	-	?-	0*	+	+	-	?+
SC	-	?-	?-	+	+	?+	-	+	?-	+
RI	0*	-	-	0*	?-	+	-	?-	+	+
TI	-	?-	?-	+	+	?+	-	-	?-	+

S3.5: Simulation input and outputs for model 3

Community matrix

	GS	CE	CC	RE	RC	SS	SE	SC	RI	TI
GS	-1	-1	0	-1	1	1	0	0	0	0
CE	-1	-1	1	0	0	0	0	0	0	0
CC	0	-1	-1	0	0	0	0	0	0	1
RE	-1	0	0	-1	1	0	0	0	0	0
RC	0	0	0	-1	-1	0	0	0	1	0
SS	-1	0	0	0	0	-1	-1	1	0	0
SE	0	0	0	0	0	-1	-1	1	0	0
SC	0	0	0	0	0	0	0	-1	0	1
RI	0	0	0	-1	0	0	0	0	-1	1
TI	0	-1	0	0	0	0	-1	0	-1	-1

Matrix determinant (must be non-zero) = 16

Number of accepted moves = 22,353

Number of loops = 100,000

Percentage of “+”

	GS	CE	CC	RE	RC	SS	SE	SC	RI	TI
GS	80.52610	23.12441	23.12441	21.56757	50.71355	97.81685	9.23813	64.47904	51.47408	45.38988
CE	8.94287	98.48790	98.48790	91.58950	63.75431	14.21286	57.80880	19.38442	25.11072	81.30452
CC	58.99432	5.60551	85.24583	50.09171	66.95298	93.38344	3.99946	40.81779	25.21362	78.43243
RE	13.54628	55.28564	55.28564	97.28448	91.95634	25.49099	52.16302	21.95231	85.07583	82.27978
RC	68.60824	21.29021	21.29021	6.71051	88.21187	98.68921	4.15157	49.42513	83.14768	69.87876
SS	1.24815	88.39977	88.39977	97.82132	53.68407	70.74218	23.50915	42.56252	35.78938	69.29271
SE	94.26923	5.20288	5.20288	19.19205	65.96430	35.72675	93.67870	90.16687	31.19939	72.43323
SC	20.10021	31.84807	31.84807	88.10898	77.63611	71.61007	8.28972	93.40133	9.91366	95.96922
RI	51.45618	23.13336	23.13336	24.16230	13.97128	97.02053	1.67763	34.03123	94.63607	85.84083
TI	20.10021	31.84807	31.84807	88.10898	77.63611	71.61007	8.28972	18.38679	9.91366	95.96922

Percentage of “-”

	GS	CE	CC	RE	RC	SS	SE	SC	RI	TI
GS	19.47390	76.87559	76.87559	78.43243	49.28645	2.18315	90.76187	35.52096	48.52592	54.61012
CE	91.05713	1.51210	1.51210	8.41050	36.24569	85.78714	42.19120	80.61558	74.88928	18.69548
CC	41.00568	94.39449	14.75417	49.90829	33.04702	6.61656	96.00054	59.18221	74.78638	21.56757
RE	86.45372	44.71436	44.71436	2.71552	8.04366	74.50901	47.83698	78.04769	14.92417	17.72022
RC	31.39176	78.70979	78.70979	93.28949	11.78813	1.31079	95.84843	50.57487	16.85232	30.11676
SS	98.75185	11.60023	11.60023	2.17868	46.31593	29.25782	76.49085	57.43748	64.21062	30.70729
SE	5.73077	94.79712	94.79712	80.80795	34.03570	64.27325	6.32130	9.83313	68.80061	27.56677
SC	79.89979	68.15193	68.15193	11.89102	22.36389	28.38993	91.71028	6.59867	90.08634	4.03078
RI	48.54382	76.86664	76.86664	75.83770	86.02872	2.97947	98.32237	65.96877	5.36393	14.15917
TI	79.89979	68.15193	68.15193	11.89102	22.36389	28.38993	91.71028	81.61321	90.08634	4.03078

Percentage of “0”

	GS	CE	CC	RE	RC	SS	SE	SC	RI	TI
GS	0	0	0	0	0	0	0	0	0	0.00000
CE	0	0	0	0	0	0	0	0	0	0.00000
CC	0	0	0	0	0	0	0	0	0	0.00000
RE	0	0	0	0	0	0	0	0	0	0.00000
RC	0	0	0	0	0	0	0	0	0	0.00447
SS	0	0	0	0	0	0	0	0	0	0.00000
SE	0	0	0	0	0	0	0	0	0	0.00000
SC	0	0	0	0	0	0	0	0	0	0.00000
RI	0	0	0	0	0	0	0	0	0	0.00000
TI	0	0	0	0	0	0	0	0	0	0.00000

Predictions table

	GS	CE	CC	RE	RC	SS	SE	SC	RI	TI
GS	+	-	-	-	0*	+	-	?+	0*	0*
CE	-	+	+	+	?+	-	0*	-	?-	+
CC	0*	-	+	0*	?+	+	-	0*	?-	+
RE	-	0*	0*	+	+	?-	0*	-	+	+
RC	?+	-	-	-	+	+	-	0*	+	?+
SS	-	+	+	+	0*	?+	-	0*	?-	?+
SE	+	-	-	-	?+	?-	+	+	?-	?+
SC	-	?-	?-	+	+	?+	-	+	-	+
RI	0*	-	-	-	-	+	-	?-	+	+
TI	-	?-	?-	+	+	?+	-	-	-	+

S3.6: Simulation input and outputs for alternative model

Community matrix

	GS	CE	CC	RE	RC	SS	SE	SC	RI	TI
GS	-1	-1	0	-1	1	1	0	0	0	0
CE	-1	-1	-1	0	0	0	0	0	0	0
CC	0	-1	-1	0	0	0	0	0	0	1
RE	-1	0	0	-1	-1	0	0	0	0	0
RC	0	0	0	-1	-1	0	0	0	1	0
SS	-1	0	0	0	0	-1	-1	1	0	0
SE	0	-1	0	-1	0	-1	-1	1	0	0
SC	0	0	0	0	0	0	0	-1	0	1
RI	0	0	0	-1	0	0	0	0	-1	1
TI	0	-1	0	0	0	0	-1	0	-1	-1

Matrix determinant (must be non-zero) = -6

Number of accepted moves = 1,458

Number of loops = 100,000

Percentage of “+”

	GS	CE	CC	RE	RC	SS	SE	SC	RI	TI
GS	89.16324	51.50892	48.49108	43.89575	71.33059	95.40466	6.10425	56.17284	56.51578	67.96982
CE	31.41289	97.39369	2.60631	30.31550	56.03567	16.11797	86.83128	57.33882	73.18244	22.35940
CC	42.59259	12.96296	98.01097	85.73388	23.79973	61.31687	25.24005	32.30453	12.20850	77.70919
RE	23.52538	50.96022	49.03978	96.91358	3.42936	4.73251	97.25652	55.69273	22.56516	15.15775
RC	59.53361	50.27435	49.72565	13.64883	97.80521	90.94650	3.15501	34.97942	86.96845	90.12346
SS	4.32099	87.92867	12.07133	86.62551	8.09328	44.92455	80.04115	76.88615	30.04115	8.71056
SE	89.09465	5.55556	94.44444	30.45267	78.39506	79.97257	54.32099	78.94376	35.25377	95.81619
SC	14.06036	50.75446	49.24554	96.70782	4.66392	25.17147	46.63923	96.98217	3.49794	73.59396
RI	41.42661	48.69684	51.30316	44.71879	51.09739	75.17147	9.25926	26.33745	89.84911	91.97531
TI	14.06036	50.75446	49.24554	96.70782	4.66392	25.17147	46.63923	26.68038	3.49794	73.59396

Percentage of “-”

	GS	CE	CC	RE	RC	SS	SE	SC	RI	TI
GS	10.83676	48.49108	51.50892	56.10425	28.66941	4.59534	93.89575	43.82716	43.48422	32.03018
CE	68.58711	2.60631	97.39369	69.68450	43.96433	83.88203	13.16872	42.66118	26.81756	77.64060
CC	57.40741	87.03704	1.98903	14.26612	76.20027	38.68313	74.75995	67.69547	87.79150	22.29081
RE	76.47462	49.03978	50.96022	3.08642	96.57064	95.26749	2.74348	44.30727	77.43484	84.84225
RC	40.46639	49.72565	50.27435	86.35117	2.19479	9.05350	96.84499	65.02058	13.03155	9.87654
SS	95.67901	12.07133	87.92867	13.37449	91.90672	55.07545	19.95885	23.11385	69.95885	91.28944
SE	10.90535	94.44444	5.55556	69.54733	21.60494	20.02743	45.67901	21.05624	64.74623	4.18381
SC	85.93964	49.24554	50.75446	3.29218	95.33608	74.82853	53.36077	3.01783	96.50206	26.40604
RI	58.57339	51.30316	48.69684	55.28121	48.90261	24.82853	90.74074	73.66255	10.15089	8.02469
TI	85.93964	49.24554	50.75446	3.29218	95.33608	74.82853	53.36077	73.31962	96.50206	26.40604

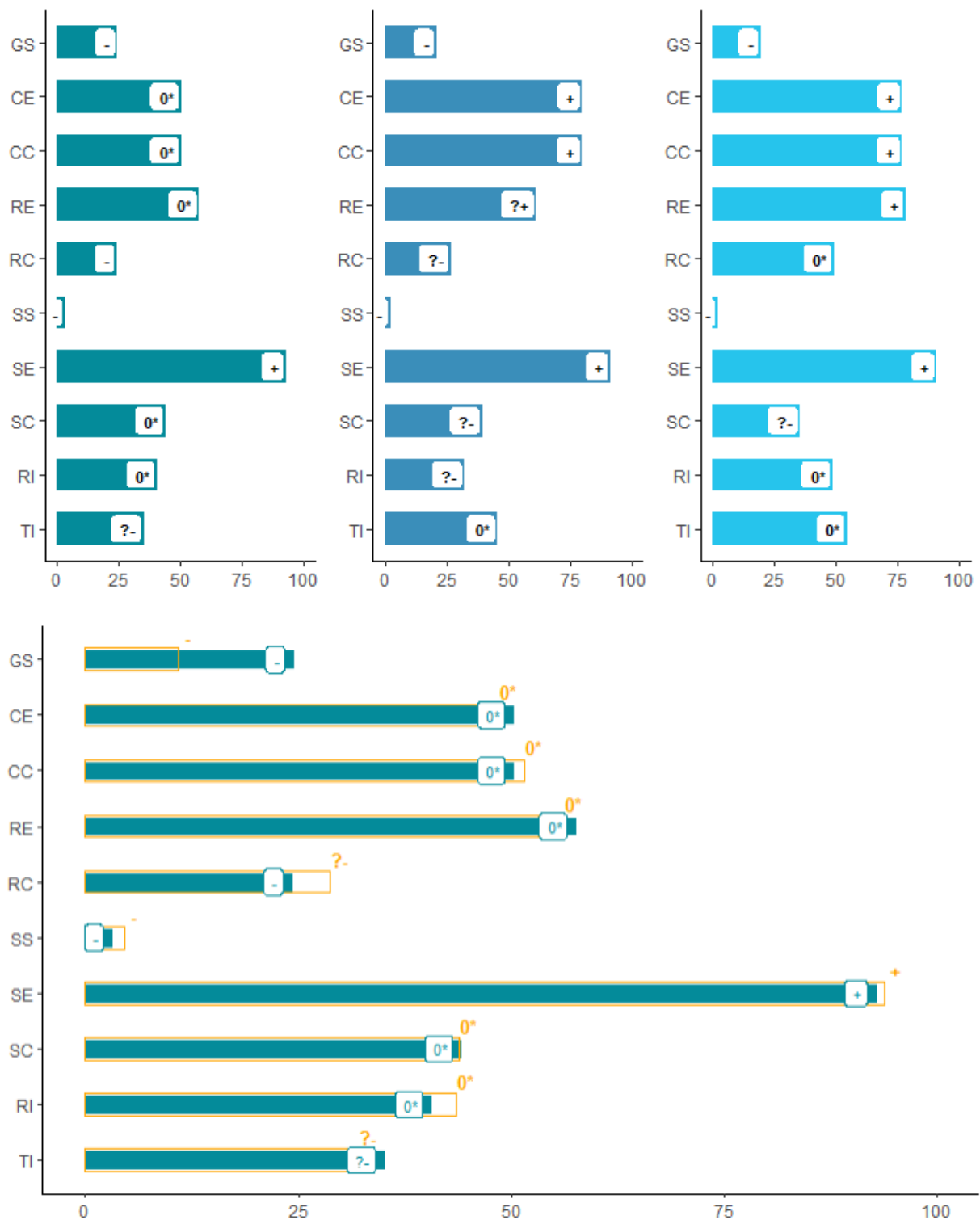
Percentage of “0”

	GS	CE	CC	RE	RC	SS	SE	SC	RI	TI
GS	0	0	0	0	0	0	0	0	0	0
CE	0	0	0	0	0	0	0	0	0	0
CC	0	0	0	0	0	0	0	0	0	0
RE	0	0	0	0	0	0	0	0	0	0
RC	0	0	0	0	0	0	0	0	0	0
SS	0	0	0	0	0	0	0	0	0	0
SE	0	0	0	0	0	0	0	0	0	0
SC	0	0	0	0	0	0	0	0	0	0
RI	0	0	0	0	0	0	0	0	0	0
TI	0	0	0	0	0	0	0	0	0	0

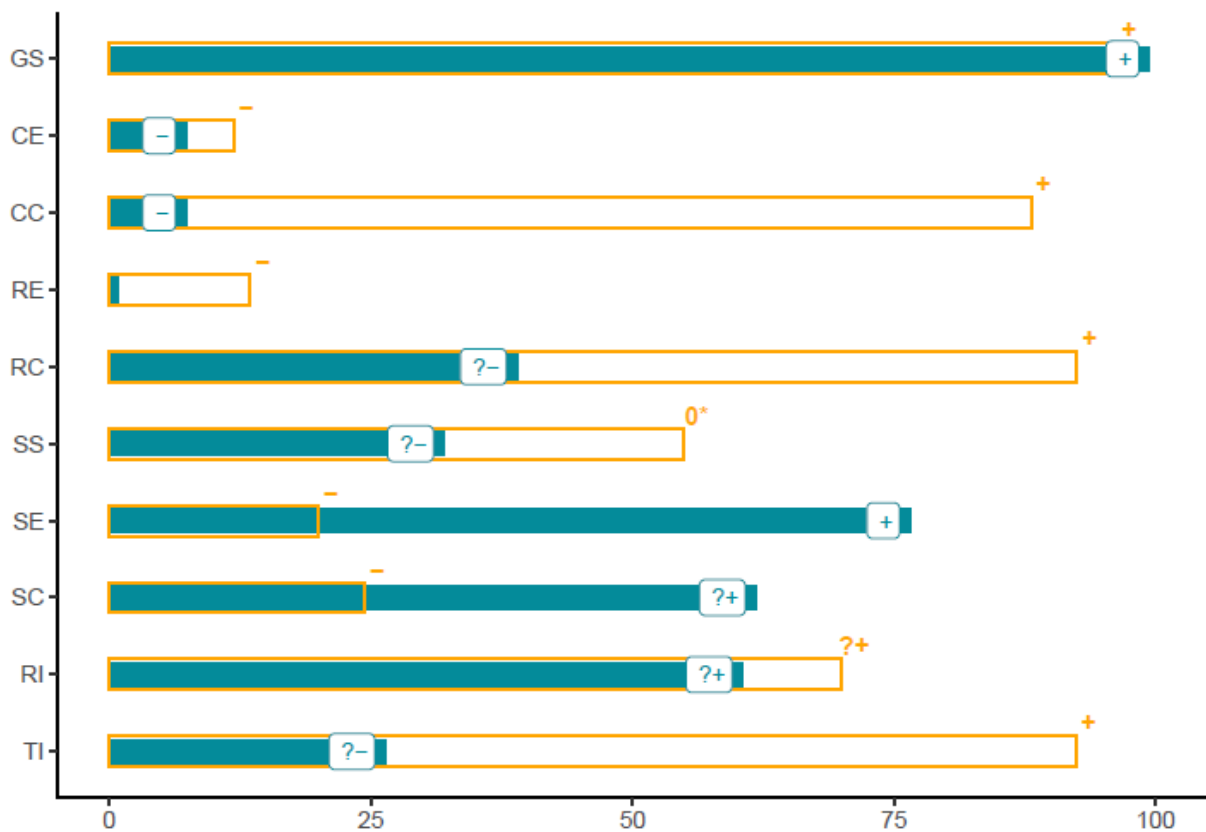
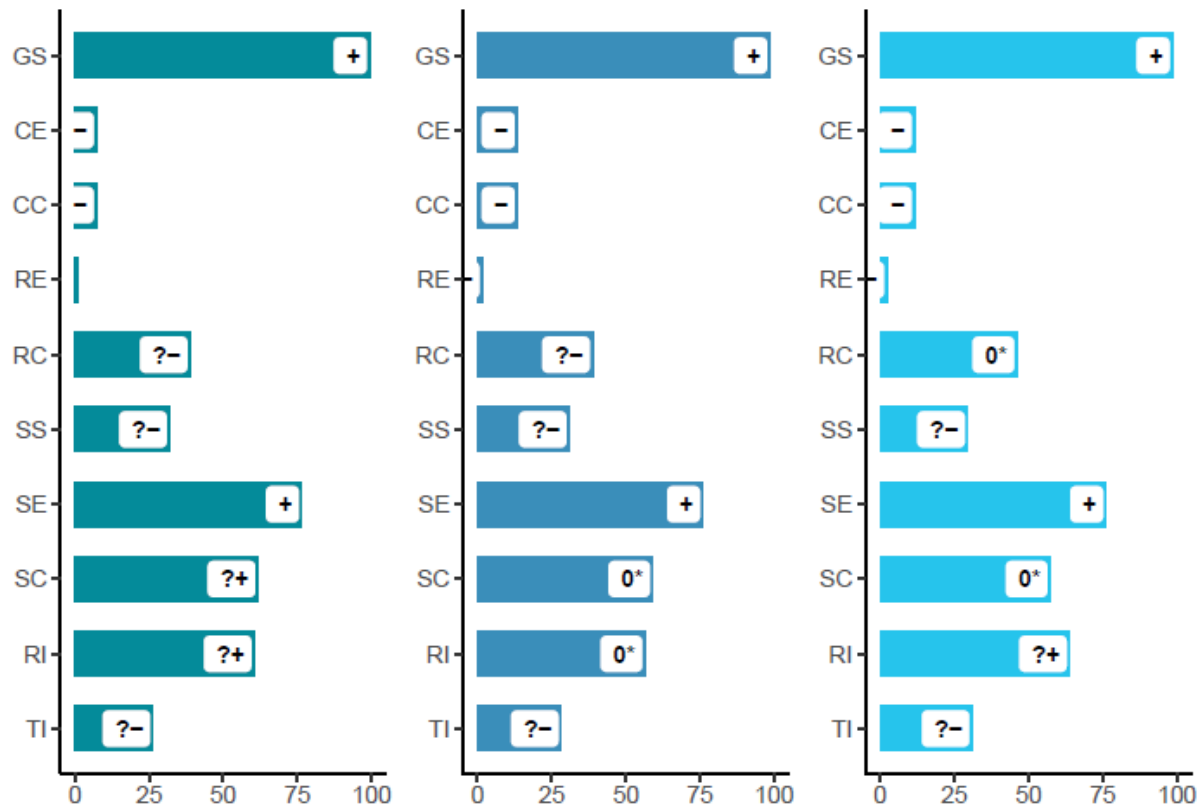
Predictions table

	GS	CE	CC	RE	RC	SS	SE	SC	RI	TI
GS	+	0*	0*	0*	?+	+	-	0*	0*	?+
CE	?-	+	-	?-	0*	-	+	0*	?+	-
CC	0*	-	+	+	-	?+	?-	?-	-	+
RE	-	0*	0*	+	-	-	+	0*	-	-
RC	0*	0*	0*	-	+	+	-	?-	+	+
SS	-	+	-	+	-	0*	+	+	?-	-
SE	+	-	+	?-	+	+	0*	+	?-	+
SC	-	0*	0*	+	-	?-	0*	+	-	?+
RI	0*	0*	0*	0*	0*	+	-	?-	+	+
TI	-	0*	0*	+	-	?-	0*	?-	-	?+

S3.7: Simulation outputs for glass eel collapse (models 1, 2, 3 from left to right, and model 1 (blue) VS alternative model (orange) bellow)



S3.8: Simulation outputs for sea-bass collapse (models 1, 2, 3 from left to right, and model 1 (blue) VS alternative model (orange) bellow)



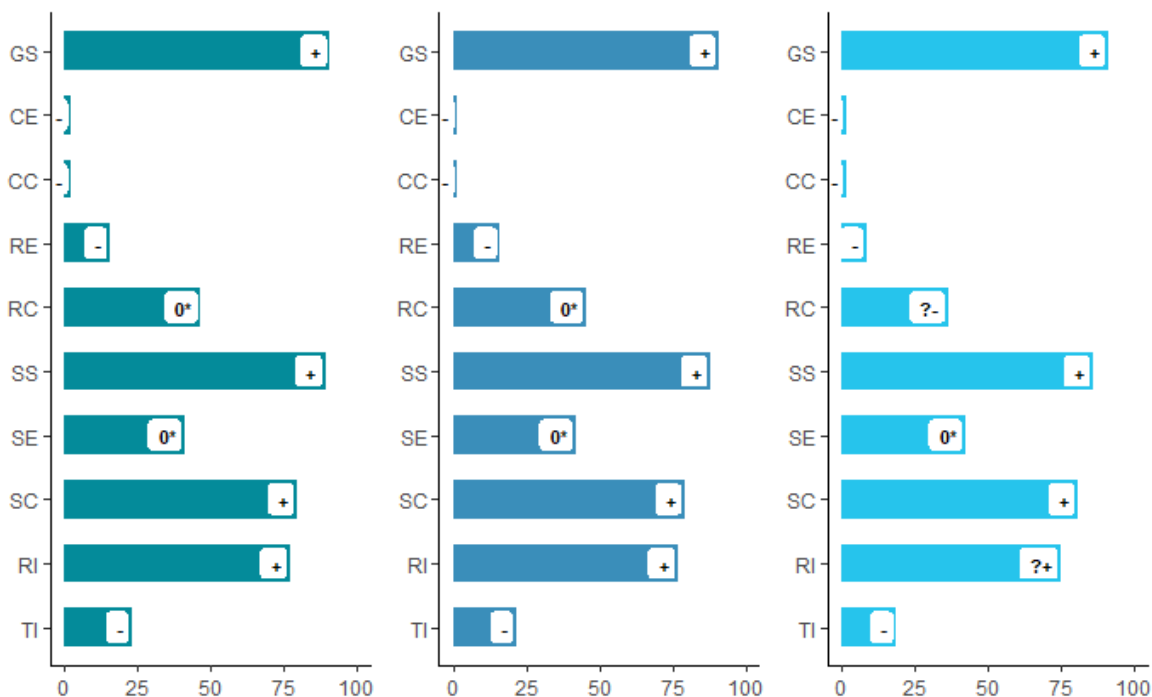
S3.9: Simulation outputs for scenario 1 (models 1, 2, 3 from left to right)

Decrease in the consumption quota (decrease in catch for consumption purposes)



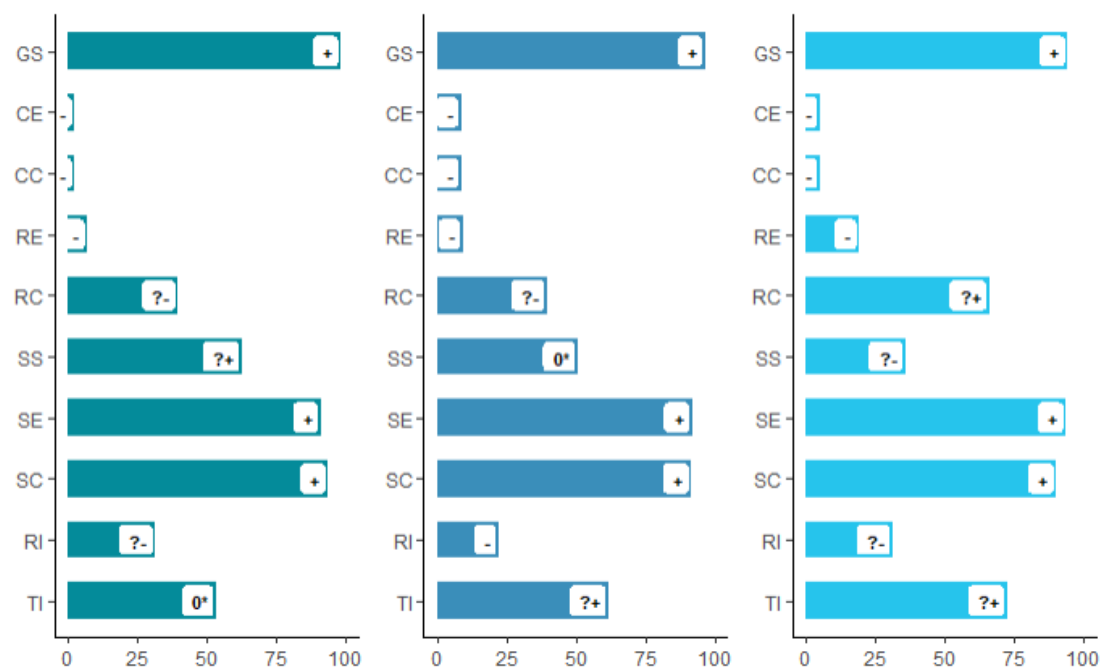
S3.10: Simulation outputs for scenario 2 (models 1, 2 and 3 from left to right)

Decrease in the fishing effort for consumption



S3.11: Simulation outputs for scenario 3 (models 1, 2 and 3 from left to right)

Encouraging the fishing of another complementary/accompanying species (increase in the sea-bass fishing effort)



S3.12: Simulation outputs for scenario 4 (models 1, 2 and 3 from left to right)

Direct subsidy to fishermen: increase in total fishing income



S3.13: Simulation outputs for scenario 5 (models 1, 2 and 3 from left to right)

Cross-subsidy: tax on fish traders to finance restocking (increase in restocking income)



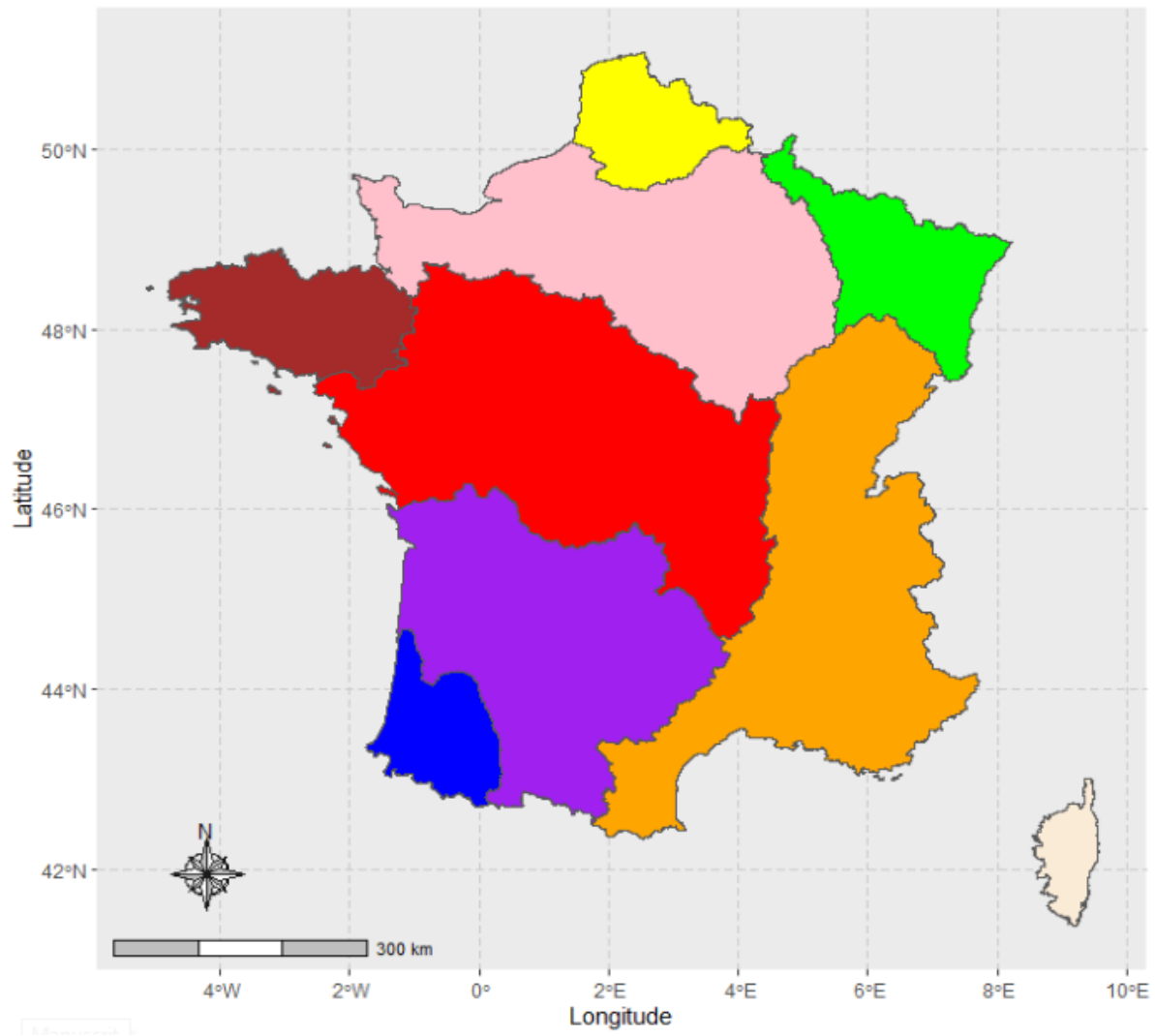
Conclusion (S4)

S4.1. Objectives of the survey and sample

	Objective	Done
Area (Basin Unit)		
1. Adour	150	151
2. Artois-Picardie	150	151
3. Bretagne	150	151
4. Garonne	150	152
5. Loire	150	151
6. Rhin-Meuse	150	151
7. Rhône-Méditerranée	150	153
8. Seine-Normandie	150	151
	1200	1211
Commune density *		
1	465	469
2	335	338
3	356	358
4	44	46
	1200	1211
Questionnaire version		
1 - Video with information - Block 1	300	302
2 - Video with information - Block 2	300	305
3 - Video without information - Block 1	300	300
4 - Video without information - Block 2	300	304
	1200	1211

* <https://www.insee.fr/fr/information/2114627>

S4.2. Map of the management Basin Units in France



8 basin units interested us in this survey: Artois-Picardie (yellow), Seine-Normandie (pink), Rhin-Meuse (green), Bretagne (brown), Loire, Côtier Vendéen et Sèvre Niortaise (red), Garonne-Dordogne-Charente-Seudre-Leyre (purple), Adour (blue), Rhône-Méditerranées (orange)

S4.3. Questionnaire (in French)

Bonjour,

Bienvenue sur ce questionnaire.

Cette enquête s'inscrit dans le cadre d'une recherche menée par des chercheur.euses de l'INRAE. Aucune connaissance particulière n'est attendue, le but de ce questionnaire est de recueillir votre opinion.

Merci de votre participation.

Votre profil

40. Etes-vous : (un seul choix possible)

- ☐ Une femme
- ☐ Un homme
- ☐ Autre

41. Quelle est votre année de naissance ? (quatre chiffres) _ _ _ _

42. Quel est votre code postal ? (cinq chiffres) _ _ _ _ _

43. Quel est le plus haut niveau d'études (ou diplôme) que vous ayez atteint ? (un seul choix possible)

- ☐ Aucun diplôme
- ☐ Certificat d'études primaires
- ☐ CAP, BEP, BEPC
- ☐ Bac ou équivalent
- ☐ Licence ou équivalent Bac+3
- ☐ Master ou équivalent bac +5
- ☐ Plus de bac + 5

44. Quelle est votre catégorie socio-professionnelle ? (un seul choix possible)

- ☐ Etudiant·e
- ☐ Agriculteur·trice
- ☐ Artisan·e, commerçant·e, dirigeant·e d'entreprise
- ☐ Cadre et profession intellectuelle
- ☐ Profession intermédiaire
- ☐ Employé·e
- ☐ Ouvrier·ère
- ☐ Retraité·e
- ☐ Sans activité

Si vous êtes en recherche d'emploi, merci d'indiquer votre emploi précédent.

45. Combien de personnes (y compris vous-mêmes) vivent dans votre foyer et sont âgées de : (remplir le tableau)

0-14ans	
14-18ans	
Plus de 18 ans	

46. Dans quelle tranche de revenus disponibles mensuels brut (salaire, pension et autres revenus, allocations familiales etc.) se situe votre foyer ? (un seul choix possible)

- ☐ Inférieur à 1180 €/mois
- ☐ De 1180 à 1560 €/mois
- ☐ De 1560 à 1880 €/mois
- ☐ De 1880 à 2230 €/mois
- ☐ De 2230 à 2620 €/mois
- ☐ De 2620 à 3100 €/mois
- ☐ De 3100 à 3660 €/mois
- ☐ De 3660 à 4390 €/mois
- ☐ De 4390 à 5600 €/mois
- ☐ Supérieur à 5600 €/mois

47. Votre activité professionnelle ou votre formation sont (étaient)-elles en lien avec le domaine de : (cocher oui ou non, on n'écarte pas les répondants qui travaillent dans ces domaines)

- ☐ La pêche Oui ☐ / Non ☐
- ☐ La gestion de l'eau Oui ☐ / Non ☐
- ☐ La conservation de la biodiversité Oui ☐ / Non ☐
- ☐ L'enseignement ou la recherche Oui ☐ / Non ☐

Votre rapport à l'environnement

48. Etes-vous membre d'une association environnementale ? (un seul choix possible)

- ☐ Oui
- ☐ Non

49. Quels sont les gestes environnementaux que vous privilégiez :

a. Au niveau de la gestion de vos déchets ? (plusieurs choix possibles)

- ☐ Vous pratiquez le tri des déchets (recyclage)
- ☐ Vous pratiquez le compostage
- ☐ Vous évitez les achats de produits à usage unique ou avec des emballages notamment en plastique
- ☐ Vous pratiquez la réutilisation (réparation, seconde main)
- ☐ Vous pratiquez le zéro déchet
- ☐ Autre _____
- ☐ Vous ne vous êtes pas penché.e sur la question

b. Au niveau de votre alimentation ? (plusieurs choix possibles)

- ☐ Vous favorisez les circuits courts
- ☐ Vous achetez des produits bio
- ☐ Vous réduisez votre consommation de viande
- ☐ Vous êtes végétarien.ne
- ☐ Autre _____
- ☐ Vous ne vous êtes pas penché.e sur la question

50. Quel est votre degré d'accord ou de désaccord avec les énoncés suivants ? (**réponse obligatoire pour chaque énoncé**)

a. Nous nous approchons du nombre limite de personnes que la terre peut nourrir

Tout à fait d'accord	D'accord	Plutôt d'accord	Je ne sais pas	Plutôt pas d'accord	Pas d'accord	Pas de tout d'accord
<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>

b. Les êtres humains ont le droit de modifier l'environnement naturel selon leurs besoins

Tout à fait d'accord	D'accord	Plutôt d'accord	Je ne sais pas	Plutôt pas d'accord	Pas d'accord	Pas de tout d'accord
<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>

c. Quand les êtres humains essaient de changer le cours de la nature cela produit souvent des conséquences désastreuses

Tout à fait d'accord	D'accord	Plutôt d'accord	Je ne sais pas	Plutôt pas d'accord	Pas d'accord	Pas de tout d'accord
<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>

d. L'ingéniosité humaine fera en sorte que nous ne rendrons pas la terre invivable

Tout à fait d'accord	D'accord	Plutôt d'accord	Je ne sais pas	Plutôt pas d'accord	Pas d'accord	Pas de tout d'accord
<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>

e. Les êtres humains sont en train de sérieusement malmener l'environnement

Tout à fait d'accord	D'accord	Plutôt d'accord	Je ne sais pas	Plutôt pas d'accord	Pas d'accord	Pas de tout d'accord
<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>

f. La terre posséderait une infinité de ressources naturelles si seulement nous savions comment en tirer mieux parti

Tout à fait d'accord	D'accord	Plutôt d'accord	Je ne sais pas	Plutôt pas d'accord	Pas d'accord	Pas de tout d'accord
<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>

g. Les plantes et les animaux ont autant le droit que les êtres humains d'exister*

Tout à fait d'accord	D'accord	Plutôt d'accord	Je ne sais pas	Plutôt pas d'accord	Pas d'accord	Pas de tout d'accord
<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>

h. L'équilibre de la nature est assez fort pour faire face aux effets des nations industrielles modernes

Tout à fait d'accord	D'accord	Plutôt d'accord	Je ne sais pas	Plutôt pas d'accord	Pas d'accord	Pas de tout d'accord
<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>

i. Malgré des aptitudes particulières, les humains sont toujours soumis aux lois de la nature

Tout à fait d'accord	D'accord	Plutôt d'accord	Je ne sais pas	Plutôt pas d'accord	Pas d'accord	Pas de tout d'accord
<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>

j. La prétendue « crise écologique » qui guette le genre humain a été largement exagérée

Tout à fait d'accord	D'accord	Plutôt d'accord	Je ne sais pas	Plutôt pas d'accord	Pas d'accord	Pas de tout d'accord
<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>

k. La terre est comme un vaisseau spatial avec un espace et des ressources très limités

Tout à fait d'accord	D'accord	Plutôt d'accord	Je ne sais pas	Plutôt pas d'accord	Pas d'accord	Pas de tout d'accord
<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>

l. Les humains ont été créés pour gouverner le reste de la nature

Tout à fait d'accord	D'accord	Plutôt d'accord	Je ne sais pas	Plutôt pas d'accord	Pas d'accord	Pas de tout d'accord
<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>

m. L'équilibre de la nature est très fragile et facilement perturbé

Tout à fait d'accord	D'accord	Plutôt d'accord	Je ne sais pas	Plutôt pas d'accord	Pas d'accord	Pas de tout d'accord
<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>

n. Les humains vont un jour apprendre suffisamment sur le fonctionnement de la nature pour pouvoir le contrôler

Tout à fait d'accord	D'accord	Plutôt d'accord	Je ne sais pas	Plutôt pas d'accord	Pas d'accord	Pas de tout d'accord
<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>

o. Si les choses continuent au rythme actuel nous allons bientôt vivre une catastrophe écologique majeure

Tout à fait d'accord	D'accord	Plutôt d'accord	Je ne sais pas	Plutôt pas d'accord	Pas d'accord	Pas de tout d'accord
<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>

51. Selon vous, qu'est-ce qu'une espèce en danger d'extinction à l'état sauvage ? (**plusieurs choix possibles**)

- ☐ Une espèce dont la population est en fort déclin
- ☐ Une espèce dont les habitats sont menacés
- ☐ Une espèce braconnée
- ☐ Une espèce dont le nombre de reproducteurs est faible
- ☐ Une espèce très commercialisée
- ☐ Je ne sais pas

52. Parmi ces espèces, lesquelles sont menacées d'extinction selon vous ? (**plusieurs choix possibles**)

- ☐ Le thon rouge de l'Atlantique (*Thunnus thynnus*)
- ☐ Le gorille (*Gorilla gorilla*)
- ☐ Le vautour fauve (*Gyps fulvus*)
- ☐ La coquille Saint-Jacques (*Pecten maximus*)
- ☐ Le mélibée (*Coenonympha hero*)
- ☐ Aucune
- ☐ Je ne sais pas

Note: pictures where added to illustrate each proposition but they have been removed in order to avoid copyright issues

53. De votre point de vue, la conservation des espèces animales en danger doit passer par : (**deux choix possibles, faire tourner les possibilités**)

- ☐ La mise en place d'aires protégées

- ☐ La mise en place de campagnes de sensibilisation auprès du grand public
- ☐ L'interdiction du commerce (des espèces et des produits dérivés)
- ☐ Le développement de l'élevage ou l'aquaculture
- ☐ La conservation ex-situ (zoos, réserves, ...)
- ☐ Autre (précisez) _____
- ☐ Je ne sais pas

54. Selon vous, quelles sont **les deux principales** menaces qui pèsent le plus sur la survie des poissons marins et d'eau douce ? (**deux choix possibles, faire tourner les possibilités**)

- ☐ Pêche illégale
- ☐ Règlementation pas assez stricte
- ☐ Pollution de l'eau
- ☐ Surpêche
- ☐ Réchauffement climatique
- ☐ Obstacles et barrières (barrages, digues, moulins, ...)
- ☐ Autre (précisez) _____
- ☐ Je ne sais pas

55. Avez-vous déjà entendu parler de l'anguille ? (**un seul choix possible**)

- ☐ Oui
- ☐ Non

56. Selon vous, quel est le statut de cette espèce ? (**plusieurs choix possible**)

- ☐ C'est une espèce invasive
- ☐ C'est une espèce nuisible
- ☐ C'est une espèce en danger d'extinction
- ☐ C'est une espèce pêchée
- ☐ C'est une espèce qui n'est pas pêchée
- ☐ C'est une espèce qui se mange
- ☐ C'est une espèce qui ne se mange pas
- ☐ Je ne sais pas

57. Selon vous, d'où proviennent majoritairement les anguilles vendues dans le commerce ? (**un seul choix possible**)

- ☐ De la pêche
- ☐ De l'aquaculture
- ☐ Des deux
- ☐ Je ne sais pas

58. Avez-vous déjà consommé de l'anguille ? (**un seul choix possible**)

- ☐ Oui
- ☐ Non
- ☐ Je ne sais pas

59. Si oui,

a. Pour quelle(s) raison(s) ? (plusieurs choix possible)

- ☐ Pour le goût
- ☐ Pour les bienfaits sur la santé
- ☐ Pour des raisons culturelles
- ☐ Parce que c'est un met de luxe
- ☐ Parce que vous en avez eu l'occasion
- ☐ Autre (précisez) _____

b. Où en avez-vous consommé ? (plusieurs choix possible)

- ☐ Au restaurant
- ☐ Chez vous
- ☐ Chez des amis/famille
- ☐ Ailleurs (précisez) _____

c. A quel(s) stade(s) de leur croissance ? (plusieurs choix possible)

- ☐ Juvénile (civelle, piballe)
- ☐ Adulte
- ☐ Je ne sais pas

d. A quelle fréquence ? (plusieurs choix possible)

- ☐ Vous n'en avez mangé qu'une seule fois
- ☐ Régulièrement
- ☐ Occasionnellement
- ☐ Uniquement pour des événements spéciaux

60. Si non : pour quelle(s) raison(s) ? (plusieurs choix possible)

- ☐ Cela ne vous tente pas
- ☐ Vous n'avez pas eu l'occasion
- ☐ Ça coûte trop cher
- ☐ C'est mauvais pour la santé
- ☐ Autre (précisez) _____

61. Avez-vous déjà pêché de l'anguille ? (plusieurs choix possible)

- ☐ Oui
- ☐ Non

62. Si oui, était-ce : (plusieurs choix possible)

- ☐ A des fins professionnelles
- ☐ Pour le loisir

63. Si oui, à quel(s) stade(s) de leur croissance étaient-elles ? (plusieurs choix possible)

- ☐ Juvéniles (civelle, piballe)
- ☐ Adultes
- ☐ Je ne sais pas

64. Une personne de votre entourage a-t-elle déjà pêché de l'anguille ? (plusieurs choix possible)

- ☐ Oui, un member de ma famille
- ☐ Oui, un.e ami.e
- ☐ Oui, une connaissance
- ☐ Non

65. Si oui, était-ce : (plusieurs choix possible)

- ☐ A des fins professionnelles
- ☐ Pour le loisir

66. Si oui, à quel(s) stade(s) de leur croissance étaient-elles ? (plusieurs choix possible)

- ☐ Juvéniles (civelle, piballe)
- ☐ Adultes
- ☐ Je ne sais pas

La conservation de l'anguille

Cette vidéo vous donnera les informations essentielles à connaître avant de continuer le questionnaire : bon visionnage !

Pensez à activer le son pour entendre les explications ☺

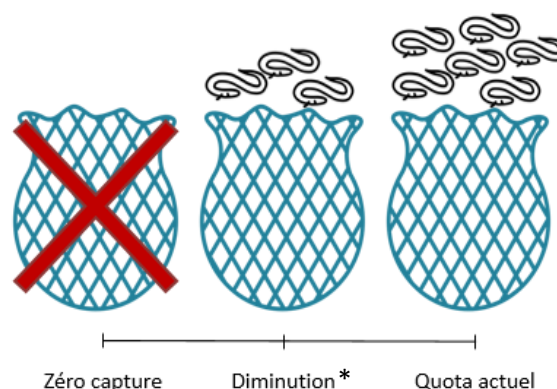
Cf fichier vidéo « avec information » et « sans information » (en fonction du questionnaire)

Dans la suite de l'enquête, plusieurs solutions de conservation de l'anguille Chacun des scénarios qui vont vous être proposées.

Chaque solution comporte 6 critères qui peuvent varier à différents niveaux :

- Critère 1 : Le quota de pêche pour la consommation

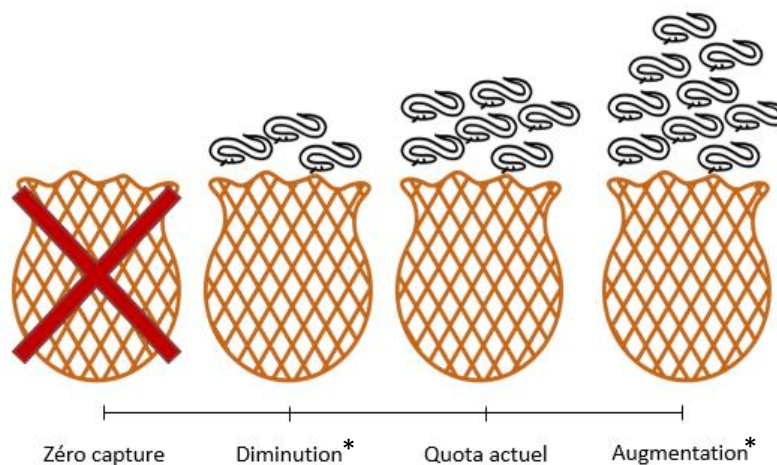
Vous pourrez choisir entre trois niveaux différents de quota de pêche pour la consommation (cf vidéo explicative) :



*Diminution par rapport au quota actuel

- **Critère 2 : Le quota de pêche pour le repeuplement**

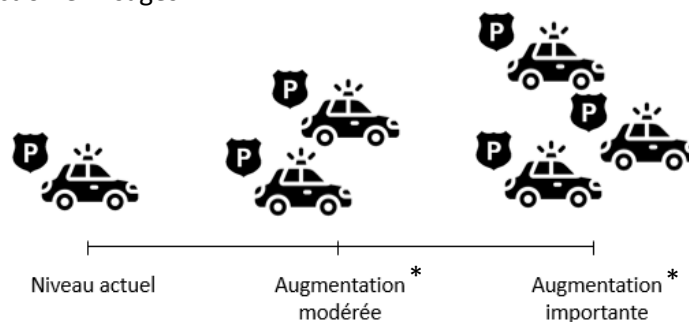
Vous pourrez choisir entre quatre niveaux différents de quota de pêche pour le repeuplement (cf vidéo explicative) selon les scénarios d'action envisagés :



*Diminution et augmentation par rapport au quota actuel

- **Critère 3 : La lutte contre le commerce illégal**

Vous pourrez choisir entre trois niveaux différents de lutte contre la vente illégale selon les scénarios d'action envisagés.



*Augmentation par rapport au niveau actuel de l'ensemble des moyens, soient de personnel, de budget, de matériel...

- **Critère 4 : La mise en place d'un label**

Vous pourrez choisir de mettre en place ou non un label permettant de tracer le produit, c'est-à-dire de connaître son origine ou de savoir s'il a été grossi en ferme d'aquaculture par exemple.



- **Critère 5 : développement de la recherche sur la reproduction**

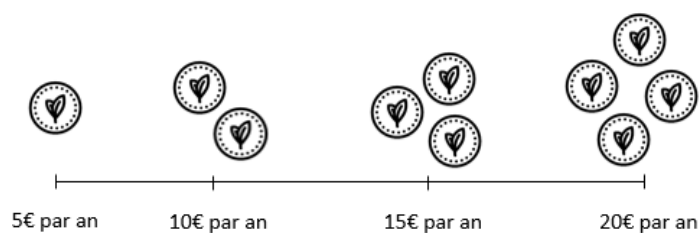
Vous pourrez choisir de développer* ou non la recherche sur la reproduction, qui pourrait permettre à terme de faire de l'aquaculture et de la reproduction artificielle d'anguille.

*Par rapport au niveau actuel



- **Critère 6 : Une contribution financière**

Vous pourrez choisir entre différents niveaux de contribution financière. Cette contribution vous serait demandée à travers la mise en place d'une taxe annuelle qui permettrait de financer la conservation de la biodiversité à hauteur de 5€, 10€, 15€ ou 20€ selon les scénarios d'action envisagés













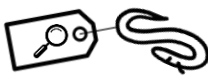






Six pages vont se succéder avec 3 options à chaque fois (en colonne)

Merci d'indiquer à chaque fois l'option qui vous satisfait le plus.




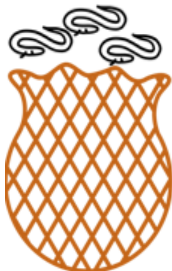













Attention : Après avoir validé un choix, vous ne pourrez pas revenir en arrière

(Mise en forme : chaque question de choix est sur une page écran. Toutes les questions de choix sont obligatoires)


















67. Première série de choix :

	Option 1	Option 2	Option 3
Quota alloué à la consommation	 Diminution	 Quota actuel	 Zéro capture
Quota alloué au repeuplement	 Augmentation	 Zéro capture	 Zéro capture
Niveau de lutte contre le commerce illégal	 Augmentation importante	 Augmentation modérée	 Niveau actuel
Mise en place d'un label	 Non	 Oui	 Non
Développement de la recherche sur la reproduction artificielle de l'anguille européenne	 Oui	 Non	 Non
Montant de la taxe servant à financer la conservation de la biodiversité	 15€ par an	 10€ par an	 0 € par an
Votre choix :	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>

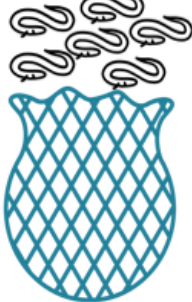
















68. Deuxième série de choix :

	Option 1	Option 2	Option 3
Quota alloué à la consommation	 Quota actuel	 Zéro capture	 Zéro capture
Quota alloué au repeuplement	 Diminution	 Zéro capture	 Zéro capture
Niveau de lutte contre le commerce illégal	 Augmentation modérée	 Augmentation importante	 Niveau actuel
Mise en place d'un label	 Non	 Oui	 Non
Développement de la recherche sur la reproduction artificielle de l'anguille européenne	 Non	 Oui	 Non
Montant de la taxe servant à financer la conservation de la biodiversité	 10€ par an	 15€ par an	0 € par an
Votre choix :	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>

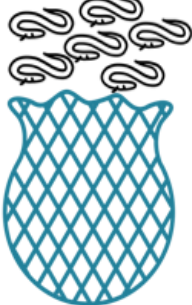
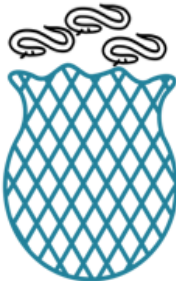















69. Troisième série de choix :

	Option 1	Option 2	Option 3
Quota alloué à la consommation	 Zéro capture	 Zéro capture	 Zéro capture
Quota alloué au repeuplement	 Augmentation	 Augmentation	 Zéro capture
Niveau de lutte contre le commerce illégal	 Niveau actuel	 Augmentation modérée	 Niveau actuel
Mise en place d'un label	 Oui	 Non	 Non
Développement de la recherche sur la reproduction artificielle de l'anguille européenne	 Non	 Oui	 Non
Montant de la taxe servant à financer la conservation de la biodiversité	 20€ par an	 5€ par an	0 € par an
Votre choix :	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>


















70. Quatrième série de choix :

	Option 1	Option 2	Option 3
Quota alloué à la consommation	 <p>Quota actuel</p>	 <p>Diminution</p>	 <p>Zéro capture</p>
Quota alloué au repeuplement	 <p>Zéro capture</p>	 <p>Augmentation</p>	 <p>Zéro capture</p>
Niveau de lutte contre le commerce illégal	 <p>Augmentation importante</p>	 <p>Niveau actuel</p>	 <p>Niveau actuel</p>
Mise en place d'un label	 <p>Oui</p>	 <p>Oui</p>	 <p>Non</p>
Développement de la recherche sur la reproduction artificielle de l'anguille européenne	 <p>Oui</p>	 <p>Non</p>	 <p>Non</p>
Montant de la taxe servant à financer la conservation de la biodiversité	 <p>10€ par an</p>	 <p>15€ par an</p>	<p>0 € par an</p>
Votre choix :	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>

71. Cinquième série de choix :

	Option 1	Option 2	Option 3
Quota alloué à la consommation	 Quota actuel	 Diminution	 Zéro capture
Quota alloué au repeuplement	 Diminution	 Zéro capture	 Zéro capture
Niveau de lutte contre le commerce illégal	 Niveau actuel	 Augmentation modérée	 Niveau actuel
Mise en place d'un label	 Non	 Oui	 Non
Développement de la recherche sur la reproduction artificielle de l'anguille européenne	 Non	 Oui	 Non
Montant de la taxe servant à financer la conservation de la biodiversité	 5€ par an	 20€ par an	0 € par an
Votre choix :	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>

72. Sixième série de choix :

	Option 1	Option 2	Option 3
Quota alloué à la consommation	 Zéro capture	 Diminution	 Zéro capture
Quota alloué au repeuplement	 Quota actuel	 Diminution	 Zéro capture
Niveau de lutte contre le commerce illégal	 Niveau actuel	 Augmentation modérée	 Niveau actuel
Mise en place d'un label	 Oui	 Non	 Non
Développement de la recherche sur la reproduction artificielle de l'anguille européenne	 Oui	 Non	 Non
Montant de la taxe servant à financer la conservation de la biodiversité	 15€ par an	 10€ par an	0 € par an
Votre choix :	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>

73. Que diriez-vous des choix que vous venez de faire ?

Très difficile	Difficile	Ni facile, ni difficile	Facile	Très facile
<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>

74. Vous avez choisi de façon :

Très certaine	Certaine	Ni certaine, ni incertaine	Incertaine	Très incertaine
<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>

75. Vous avez choisi au moins une fois l'option « zéro capture » pour quelle(s) raison(s) ? (uniquement pour les répondants ayant choisi au moins une fois cette option) (**plusieurs réponses possibles**).

- ☐ Je ne crois pas que les autres mesures de régulations proposées soient efficaces
- ☐ Je ne souhaite pas payer de taxes supplémentaires
- ☐ Je ne me sens pas vraiment concerné·e par le déclin de la population d'anguille européenne
- ☐ Je ne pense pas avoir les moyens de payer le montant proposé
- ☐ Autres (veuillez préciser) _____

S4.4. Script of the video (in French)

Note: the yellow part is the additional information

Dans la suite de ce questionnaire, vous allez devoir choisir entre plusieurs scénarios de conservation de l'anguille européenne. En effet, l'anguille européenne est classée comme espèce en danger critique d'extinction sur la liste rouge de l'union internationale pour la conservation de la nature, c'est pire que pour le panda ! Sa population ne cesse de décroître depuis plusieurs décennies. En effet, le nombre d'anguilles, a chuté de plus de 90% ces 40 dernières années ! Pour remédier à ça, plusieurs mesures ont été mises en place par les différents pays européens où l'on peut pêcher de l'anguille, et dont la France fait partie. Parmi ces actions, une nous intéresse tout particulièrement : le repeuplement. Ça consiste à prélever des anguilles à un endroit puis à les remettre dans un autre plan d'eau dans le but d'augmenter une population existante ou d'en créer une nouvelle. Alors attention, contrairement à ce qui est fait sur d'autres espèces, le repeuplement de l'anguille est réalisé à partir d'individus sauvages. En France, le repeuplement est réalisé avec de jeunes anguilles, que l'on appelle les civelles. Les pêcheurs professionnels sont à la base du repeuplement puisque ce sont eux qui fournissent les civelles qui vont être relâchées. Pour la saison de pêche de 2020-2021 par exemple, les pêcheurs professionnels de civelles français disposaient d'un quota total de 57,5 tonnes. 60% de ce quota était alloué au repeuplement tandis que les 40% restant étaient alloués à la consommation. Le quota total est réévalué tous les ans, mais les proportions allouées au repeuplement et à la consommation restent de 60 et 40 %. La côté Atlantique française abrite la plus grosse population d'anguilles européennes et c'est donc ici que l'on en pêche le plus. Mais vous vous êtes peut-être dit que 57,5 tonnes, c'est beaucoup, et vous auriez raison. Les quantités de civelles pêchées en France ne sont pas toutes consommées ou utilisées pour le repeuplement dans le pays. Une partie de ces captures est exportée dans d'autres pays de l'Union Européenne, et de l'Union Européenne seulement, puisqu'en 2010, les exports en dehors des pays de l'UE ont été interdits. Cependant, les civelles pêchées en France et dans les autres pays européens sont parfois exportés illégalement afin de combler la demande des plus gros consommateurs d'anguille. Historiquement, ce sont les Japonais qui ont le plus consommé l'anguille. Aujourd'hui, les Chinois sont en tête et consomment 62% des anguilles pêchées, toutes espèces confondues.

Comme je le disais, la demande asiatique n'est pas couverte avec la pêche locale et un marché noir s'est mis en place on a constaté que des quantités importantes de civelles étaient exportées des pays européens aux pays asiatiques comme vous pouvez le voir sur les cartes qui s'affichent. On estime que 25 à 50 tonnes de civelles sont exportées illégalement de l'UE tous les ans.

Vous avez maintenant toutes les informations clés en main pour répondre à la suite du questionnaire !

S4.5. The attributes and levels in the choice experiment

Attributs denomination	Levels
Introduction of an annual tax to fund biodiversity conservation	0€ (reference scenario) 5€ 10€ 15€ 20€
Fishing quota for consumption	Zero catch (reference scenario) Diminution Current level
Fishing quota for conservation (restocking)	Zero catch (reference scenario) Diminution Current level Augmentation
Fight against illegal exports/trade flows (increase in all resources = staff, budget, equipment, etc.)	Current level (reference scenario) Low increase High increas
Setting up a label (traceability, origin, farmed or wild)	No (reference scenario) Yes
Developing research on artificial eel reproduction	No (reference scenario) Yes

Note: for the reference situation, the current situation levels were offered (status quo) for every attributes excepted for quotas as one aim of this study was to test the zero catch scenario introduced by the ICES advice (2021)