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Development of a framework for management objectives and associated tools for the invasive Pacific oyster, *Magallana gigas*, on the Swedish west coast

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Abstract

Introductions of marine invasive alien species are often mediated through transportation of goods or aquaculture projects. When a species is introduced there is a risk of negative consequences for native biodiversity, but also for human health and economies. In order to minimize negative effects, management is needed. Current models for management of invasive species are, however, usually general and hard to apply in local contexts.

The Pacific oyster (*Magallana gigas*) is an example of an invasive species that established abundant populations along the Swedish west coast in 2006. As with other invasive species, the Pacific oyster can have negative consequences, such as endangering other bivalves with similar niches and replacing soft bottom habitats. However, several positive effects have been observed too, i.e., contributing to increased diversity of infauna and epifauna as well as acting as nurseries for other species.

Despite being established for over 15 years, no management is currently implemented for the species due to lack of suitable management objectives on local and national scale. Therefore, a framework including management objectives and associated tools based on different stages of invasion for the species was developed in this thesis. Several objectives and sub-objectives were identified for each invasion stage and connected to an array of management tools, all found through a structured literature review. Additionally, stakeholder's knowledge regarding management of the Pacific oyster was evaluated and revealed low knowledge levels as well as a need for support in management.

In order to implement a framework such as this there are several prerequisites that must be met, e.g., access to the oysters, which currently belong to landowners, implementation of innovative food safety protocols, and development of markets for new, untraditional, oyster products. For successful implementation, the framework should also be further connected to methods e.g., for culling.

Popular Scientific Summary

The Pacific oyster (*Magallana gigas*) is a species that originally was not found in Swedish water and is therefore considered invasive. Since 2006, the oyster has been observed along the Swedish west coast. When an alien species is introduced to a new environment there is a risk that it might cause damage to native animals and plants, but also to human health and economies. This applies to the Pacific oyster as the oyster potentially could outcompete similar animals for space and food. There is also a risk of their sharp shells causing harm to beachgoers in recreational areas. In order to reduce the negative impacts of introduced invasive species, it is important to implement management. However, the Pacific oysters have been observed to contribute with several positive effects as well, such as providing shelter and acting as nursery for other species, something that also should be considered in management.

There are already existing models that provide guidance of how invasive species can be managed, but they are usually general and are therefore hard to apply in local contexts. By conducting a literature review, this thesis developed a framework for management based on different stages of invasion for the Pacific oyster. The framework includes several objectives and sub-objectives for each invasion stage identified through a structured literature review and connect the objectives to an array of management tools and techniques. By identifying what invasion stage a locality is in and connecting this to the correct stage in the framework, clear directions for management is provided. Moreover, stakeholder's knowledge regarding management of the Pacific oyster was investigated and showed low knowledge levels as well as a need for support in management, supporting the identified need for the developed framework.

The current regulatory framework related to the Pacific oyster in Sweden, however, prevents implementation of a framework such as the one developed here. In order for implementation to be successful, access to the oysters (which currently belong to the landowners) must be granted, protocols for food safety must be developed and the market for previously unutilized oyster products must be expanded. Moreover, for future implementation, the framework should also be linked to suitable management methods, e.g., for removal of oysters.

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Introduction

Invasive alien species (IAS) are species that arrive to environments they normally do not inhabit (Clinton, 1999). IAS introductions are almost always facilitated by human activities, such as transportations of goods or cultivation projects (NOAA, 2019). Introductions of invasive species are likely to result in negative consequences for native biodiversity as well as human health and economies (Early et al., 2016). As introductions of IAS are likely to cause harm, it is important to implement strategies for management that help mitigate and minimize effects, while accounting for both environmental and socioeconomic impacts of the management strategies.

An example of an invasive species is *Crassostrea/Magallana gigas* (hereafter *M. gigas*, Pacific oyster or oyster) that was observed to have established abundant populations along the Swedish west coast in 2006 (Wrange et al., 2009). The Pacific oyster is mainly found in the intertidal and sub-tidal zones of sheltered areas, e.g., shallow bays and narrow sounds (Laugen et al., 2015). As an intertidal species the oyster is used to varying conditions and has a broad tolerance to both temperature and salinity variations. This, combined with its high growth rates and large reproductive output, makes the Pacific oyster a successful invader (Troost, 2010; Laugen et al., 2015).

Although there are several potential negative effects of a Pacific oyster invasion, e.g., threat to local bivalves with similar niches and replacement of softbottom habitats (Laugen et al., 2015), several positive effects of their presence have been observed. By creating reefs with a three-dimensional structure, the oysters contribute to increased abundance and diversity of both infauna and epifauna, create shelter and act as nurseries for other species, and as highly productive filter feeders they can help mitigate effects of eutrophication (Troost, 2010; Laugen et al., 2015). In addition to this, as one of the most cultivated species in the world, the Pacific oyster is of high commercial value (Laugen et al., 2015).

Today, there are models that provide guidelines for how an IAS should be managed. By distinguishing between different stages of invasions they aim to provide suitable management objectives for each stage (Fig. 1). The first, and most ideal, step of managing an invasion is to prevent it in the first place. This can be done by identifying and controlling vectors of dispersal. When a species has been introduced, but yet only present in low numbers, the optimal objective is eradication, which can be feasible when population numbers are still low. The next stage of an invasion, expansion, is characterised by rapid population growth and high dispersal rates. Here, suggested management objectives are focused on preventing further spread and creating public awareness. During the final stage, persistence, the species is fully established and abundant. Throughout the persistence stage there is a shift in management focus from eradication and containment to long-term management and mitigation efforts (Geburzi & McCarthy, 2018).

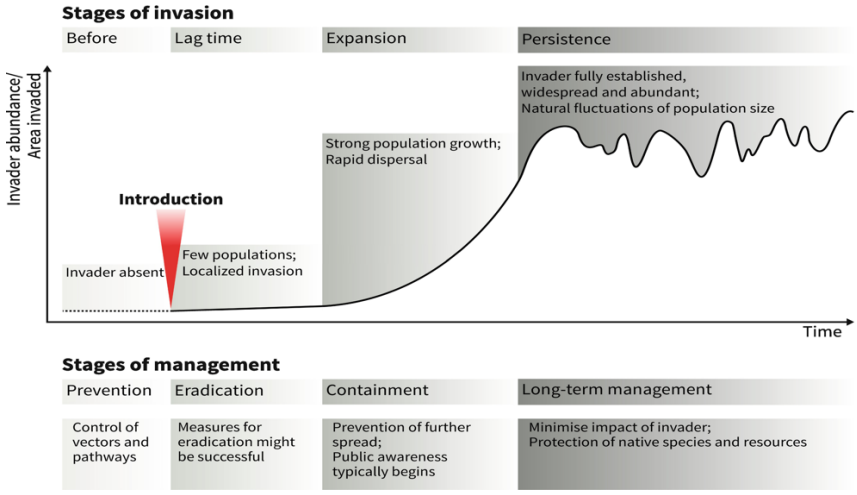

Figure 1 *Stages of invasion of an invasive alien species coupled with suitable management objectives (Geburzi & McCarthy, 2018)*

Even though current models provide recommendations for management, they tend to be general and therefore hard to apply in local contexts. In order for models to be more practical, there is a need for further development and adaptation to local situations, as well as to relate them to suitable management tools and techniques. An example of dynamic management is that of the red king crab, *Paralithodes camtschaticus*, in Norway. To achieve an effective management, the Norwegian zone of the Barents Sea has been split into two different parts. In the westernmost area, the species is not fully established, and management is therefore focused on containment and preventing further spread along the Norwegian coast. This is done by allowing free fishing of the species. In the easternmost area, were the species is fully established, a commercial fishery has been implemented in order to utilize the commercial value, while at the same time managing ecological challenges that the introduction has brought along by reducing the numbers of crabs in the area (Jørgensen & Nilssen, 2011).

Today, in Sweden, the Pacific oyster and other invasive species are managed on a national level without consideration of spatial variations. In order to develop a dynamic and more localized management model for the Pacific oyster, similar to that of the red king crab in Norway, a project called DynamO was initiated in 2021 (Svenska Miljöinstitutet IVL, 2022). To achieve the previously mentioned goal, a dynamic management adapted to specific stages of the invasion process, the project has developed a tool, currently under evaluation, for identifying different stages of an invasion (Le Gall, 2022). The objective of the model is to enable identification of at what stage of the invasion a locality is in. In order for the model to contribute to the aim of creating a more dynamic management of the Pacific oyster on the Swedish west coast there is, however, a need to connect each invasion stage to suitable

management objectives, adapted to a national and local context, as well as to identify management tools and techniques.

Purpose and Aims

The purpose of this study, as part of the DynamO project, is therefore to identify possible management objectives for the Pacific oyster in Sweden in different invasion stages and relate this to possible management tools and techniques. Additionally, stakeholders' knowledge towards various management objectives and techniques will be assessed.

Hypothesis

H_0: Current management of the Pacific oyster along the Swedish west coast is the most efficient, and no distinction in management related to differences in invasion stage in various parts along the coast is needed. Stakeholders knowledge level regarding management of the Pacific oyster is sufficient.

H_1: Management of the Pacific oyster along the Swedish west coast should be adapted to local conditions for more effective management. Stakeholders knowledge level regarding management of the Pacific oyster is insufficient.

Methods

Structured Literature Review

In order achieve the aim of creating clearer guidelines for management of the Pacific oyster along the Swedish west coast, a structured literature review was conducted. The process involved reviewing previously published material related to the topic and synthesizing it to answer the research question (Villar, n.d.).

To create a search query for the structured literature review, key concepts of the research question was identified and separated into four different search blocks (Fig. 2) according to the methodology described by Karolinska Institutet University Library, (n.d.). Key concepts were identified using the framework PEO (population, exposure, outcome) that is best suited for qualitative studies (Karolinska Institutet University Library, n.d.). In order to get relevant results, key concepts in each block were combined using the Boolean operator “OR” and separated with parentheses and combined using the operator “AND”. The use of “OR” indicates that at least one of the key concepts needs to be found in the paper, resulting in a broadening of the search, while “AND” will limit the search to papers that contain at least one of the key concepts from each search block (Karolinska Institutet University Library, n.d.).

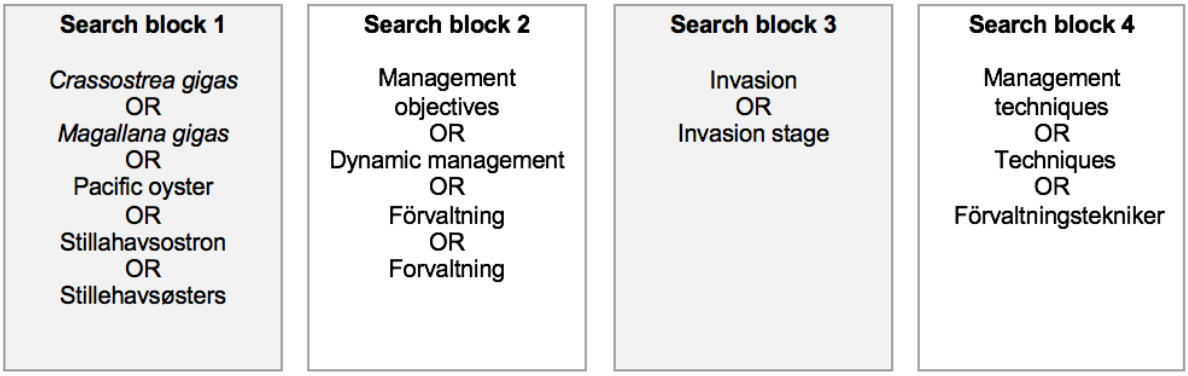

Figure 2 *Key concepts of the research question were developed and split into four different search blocks to help create a structured literature search.*

The final combination of key concepts and blocks (Table 1) were used to search the database Google Scholar. Searches were conducted between the 23rd of March and the 25th of April 2023. The structured search was complemented by a manual review, where reference lists of papers found in the first search were reviewed and relevant papers explored. Papers recommended by the supervisor were also added manually (Table 1). For papers to be included in the review, the criteria were that they had to be written in either English, Swedish, Norwegian or Danish. Therefore, key concepts were designed in a way to include relevant search hits in all languages. As all available data regarding the species and its management was of interest, no time interval for publication date was selected.

Table 1 *Final combination of key concepts and search blocks*

Date	Search terms	Database	Number of hits
23/3-2023 -	(“Crassostrea gigas” OR “Magallana gigas” OR “Pacific Oyster” OR “Stillahavsostron” OR” Stillehavsøsters”) AND (“Management objectives” OR “Dynamic Management” OR “Förvaltning” OR “Forvaltning”) AND (“Invasion” OR “Invasion stage”) AND (“Techniques” OR “Management techniques” OR “Förvaltningstekniker”)	Google Scholar	220
25/4-2023	Manual Search		9

The collection of papers used in the review were attained through two selection processes. The first selection consisted of reading title and abstract of papers found in the literature search. If that seemed of interest for the research question, it went on to the second selection. In the second selection, the complete papers were read. A framework was then used to determine the quality of the paper. The framework applied was based on a framework from the Swedish Agency for Health Technology Assessment and Assessment of Social Services’, designed for quality reviews for quantitative studies (SBU, 2020). In order to assert high quality of papers, the framework asked questions regarding purpose, data collection, analysis etc., and questions could be answered with “Yes”, “No” or “Unclear” (Appendix 1). In the end, 27 articles passed the quality review, and they were all included in the structured literature review (Appendix 2). The process of selecting and excluding articles is illustrated in Figure 3.

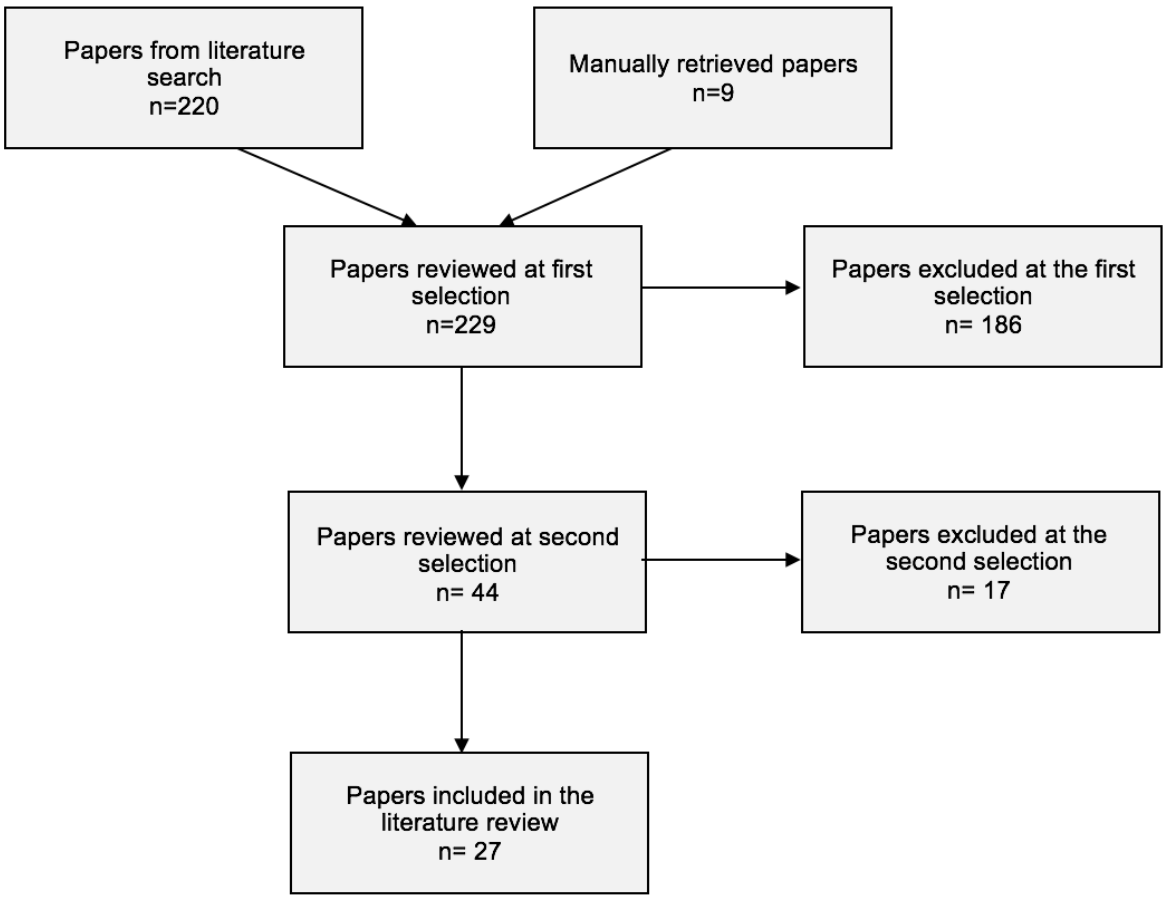

Figure 3 *Illustration of the process of selecting papers for the structured literature review.*

Stakeholder Survey

In order to investigate stakeholders' knowledge of the Pacific oyster, a survey was developed by Roesch (2023). To avoid stakeholder fatigue, questions related to attitudes and knowledge regarding management of the Pacific oyster, the focus of this thesis, was added to the survey. The survey was distributed to municipality (primarily municipality ecologist) and county administrative board stakeholders along the Swedish west coast. Selected questions related to the management part of the survey was reviewed and analyzed.

Statistical Analysis

A linear regression analysis was conducted in order to investigate if there was a significant correlation between stakeholders' knowledge level regarding management of the Pacific oyster and invasion stage. Data regarding invasion stages for the different municipalities was attained from a paper by Roesch (2023) that had revised the previous model of invasion stages by Le Gall (2022). Data for knowledge levels

was obtained from the stakeholder survey. Analysis was performed using excel. In order to conduct the analysis, both knowledge level and invasion stage had to be ranked using a numerical scale (Table 2), with the lowest number corresponding to the lowest knowledge level and least amount of oyster and then increasing with the highest number corresponding to the highest level of knowledge and the most amount of oyster.

Table 2 *Ranking of knowledge level and invasion stage*

Knowledge level	**Rating**
Low	1
Very Low	2
Medium	3
High	4
Very High	5
Invasion Stage	**Rating**
Future settlement possible	1
Survival	2
Sink	3
Source	4
Established reef/high density	5

Note: In order to perform a linear regression analysis, both knowledge level and invasion stage was ranked using a numerical scale. The lowest number corresponds to the lowest knowledge level and least amount of oyster and the highest number corresponding to the highest level of knowledge and the most amount of oyster.

Interviews with stakeholders

When a first draft of the framework for management objectives and associated tools had been developed based on data found during the literature review, it was presented to a limited group of stakeholders for feedback. The stakeholders were asked questions regarding the framework, if they deemed it easy to follow and apply in practice and if they found something to be missing or to be redundant.

Results

Structured Literature Review and Framework

The structured search resulted in 220 papers. Additionally, 9 papers were added manually based on reference lists in identified relevant articles and on supervisor recommendations. The total number of papers that passed through the two selections and were used in the literature review were 27, the process of selecting and excluding articles is illustrated in Figure 3. Most of the papers were focused on management of the Pacific oyster or bivalves, while others were more general and concentrated on marine invasive species.

7 Management objectives, 10 sub-objectives and 25 management tools were identified in the literature review and are summarized briefly below (Table 3). Based on results found in the literature review, a framework was developed with suggestions for management objectives and tools, which is available in Appendix 3. In order to create site-specific guidelines, the results were separated into sub-sections based on invasion stages described by Le Gall (2022) and Roesch (2023).

Table 3 *Summary of results found in the structured literature review*

Management objectives	• Prevent Introduction (1, 10, 12) • Resist Establishment (16) • Contingency Planning (1, 8) • Early Detection (10, 12, 18, 19) • Confinement (1, 12) • Control / Functional Eradication (1, 20) • Mitigation (1, 12)
Sub-objectives	• Control and limit vectors of dispersal (1, 8, 19) • Predict spread and future invasion (19) • Monitoring (1, 5, 7, 18, 19) • Education and public awareness (4, 8, 19) • Minimize negative effects and stresses on ecosystems (16) • Eradication of entire area (1, 16) • Prevent further establishment (1, 12) • Limit size of non-eradicable populations at specific location or entire area (3, 7, 8, 16, 17) • Limit spread of non-eradicable populations (1, 12) • Prevent establishment of populations in high value/sensitive areas (6, 8, 11, 17, 19)

Management tools	• Identify and assess vectors of dispersal (1, 8, 19) • Monitor and manage vectors of dispersal (1, 8, 19) • Develop dispersal models (8, 17, 19) • Identify areas suitable for oyster settlement (7, 8, 15, 19) • Identify natural barriers (8) • Monitor for early detection (10, 18) • Disperse information regarding species (8) • Strengthen/restore populations of important species (16) • Monitor for disease and pathogens (9, 18) • Risk assessment (8) • Develop action plan (1, 8) • Environmental impact assessment (5, 8, 16) • Implement action plan for early eradication (1, 8) • Mapping (8, 14, 17) • Identify site connectivity (8, 17) • Management harvest (2, 7, 8, 9, 13, 14, 17) • Target high density populations (11, 15) • Open access to stocks (8, 9) • Monitor development of populations (7, 11) • Continued monitoring of spread and densities (1, 5, 7, 18, 19) • Prioritize what effects to mitigate (17) • Commercial harvest (2, 7, 8, 9, 13, 14, 17) • Market development (17, 19) • Alternative tools (e.g., sand capping, competition with bivalves) (19) • Continued research (1, 5, 8, 19)

References: (1) Hillard, 2004; **(2)** Bodvin et al., 2007; **(3)** Christensen & Elmedal, 2007; **(4)** Wrange, 2008; **(5)** Herbert et al., 2012; **(6)** Bodvin et al., 2014; **(7)** Dolmer et al., 2014; **(8)** Miljødirektoratet, 2016; **(9)** Sundet et al., 2016; **(10)** Mortensen et al., 2017; **(11)** Dahl & Naustvoll, 2018; **(12)** Geburzi & McCarthy, 2018; **(13)** Giakoumi et al., 2019; **(14)** Mortensen et al., 2019; **(15)** Bergström et al., 2021; **(16)** Morgan et al., 2021; **(17)** Mortensen et al., 2022; **(18)** Nielsen et al., 2022; **(19)** Hansen et al., 2023; **(20)** Strand et al., 2023

Stakeholder Survey Analyzes

The stakeholder survey received 21 responses overall. Results showed that the general knowledge level regarding management of the Pacific oyster at municipality level was low (Fig. 4A), 38% stated that their knowledge was “very low” and 33% answered that their level was “low”, meanwhile only 5% stated that they had “high” knowledge levels. As indicated by the results, most respondents would like support in terms of the management (Fig. 4B). The results also showed that few municipalities have a management plan to handle invasions of Pacific oysters in place today and that they had not performed any type of management prior to the questionnaire (Fig. 4C). When being asked if their organization would like to be involved in management actions the most common answer was “I don’t know” (Fig. 4D).

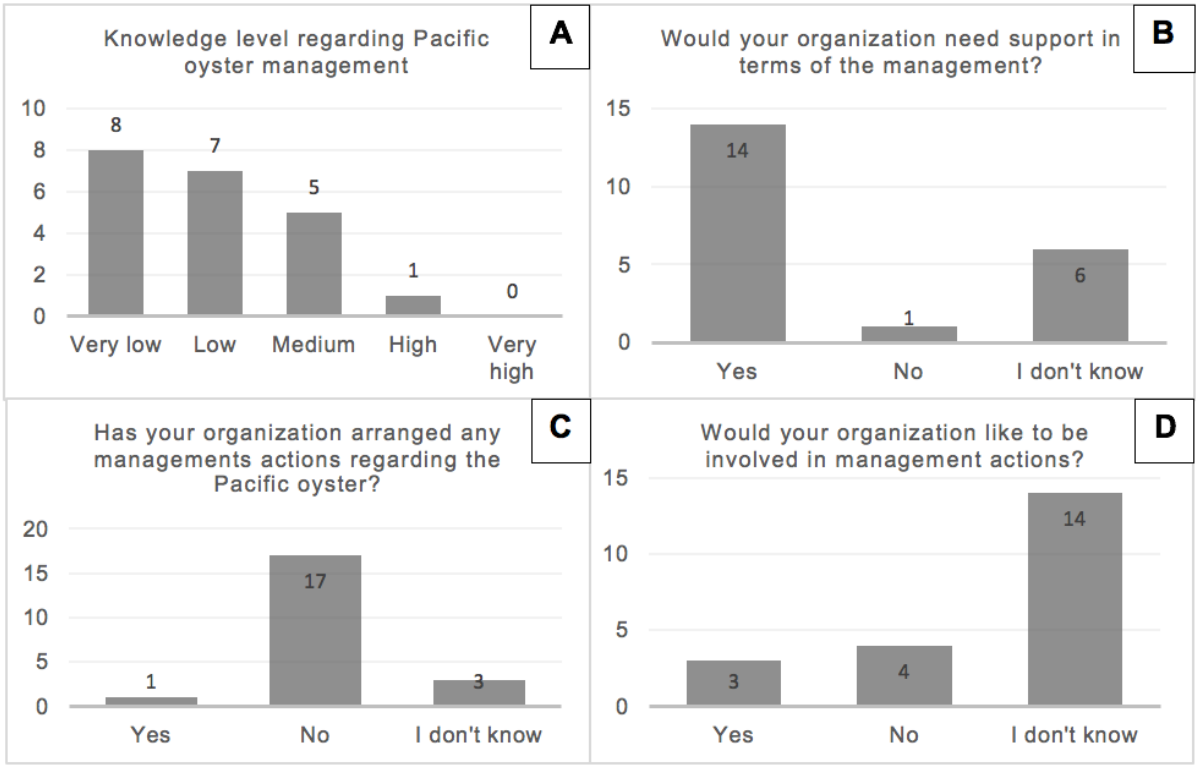

Figure 4 *Responses to the stakeholder survey regarding municipalities knowledge and attitudes to management of Pacific oysters. The y-axis represents number of answers.* ***(A)*** *Stakeholders knowledge levels regarding the management of the Pacific oyster.* ***(B)*** *Answers when being asked if they need support in terms of the management of the Pacific oyster.* ***(C)*** *Stakeholders answer to the question "Has your organization arranged any management actions regarding the Pacific oyster?".* ***(D)*** *Stakeholders answers when being asked if they want to be involved in management actions regarding the Pacific oyster.*

Furthermore, stakeholders were asked what management objectives they would deem suitable in areas with: no oysters, low densities of oysters and high densities of oysters. The questions were open-ended and analyzed by identifying key words. Although the most common answer to all stages of invasion was "No answer", some stakeholders suggested management objectives that also were identified in the structured literature review (Fig 5). The most mentioned objective for "Absence" was "Monitoring" (Fig. 5A). For "Low density", the most mentioned was "Eradication of entire area" (Fig. 5B) and for "High density" it was "Prevent further spread" (Fig. 5C).

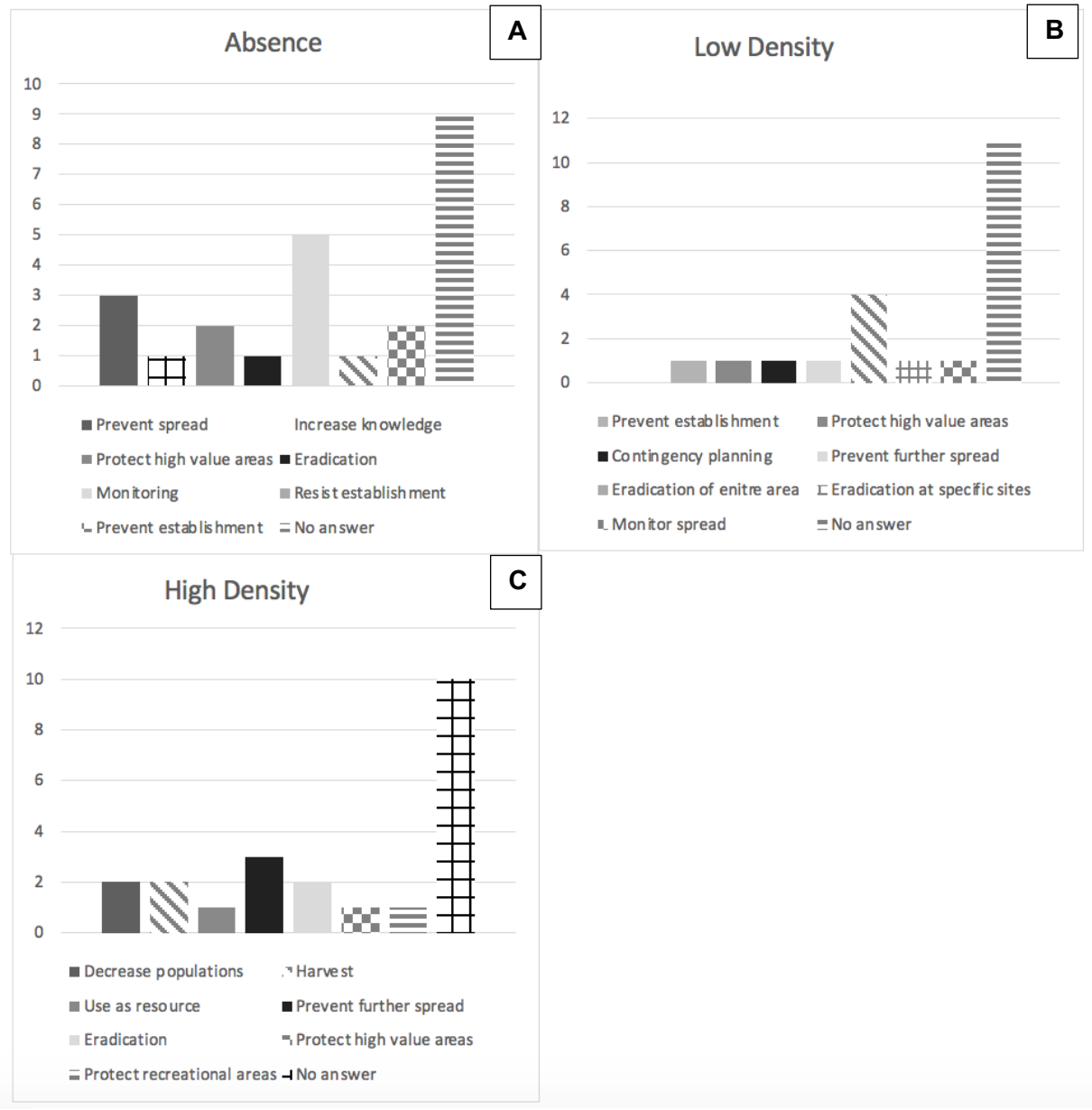

Figure 5 *Stakeholder-response when being asked what management objective(s) they deem suitable in areas with (A) No Pacific oysters, (B) Low densities of Pacific oysters and (C) High densities of Pacific oysters. The y-axis represents number of answers.*

In order to investigate if knowledge levels of stakeholders on the Swedish west coast was dependent on invasion stage a linear regression analysis was conducted. The statistical analysis revealed that no significant correlation between the dependent variable “Knowledge level” and the independent variable “Invasion stage” could be found (p-value: 0.235). Figure 6 displays the relationship between the two variables and a trendline with the predicted Y-value.

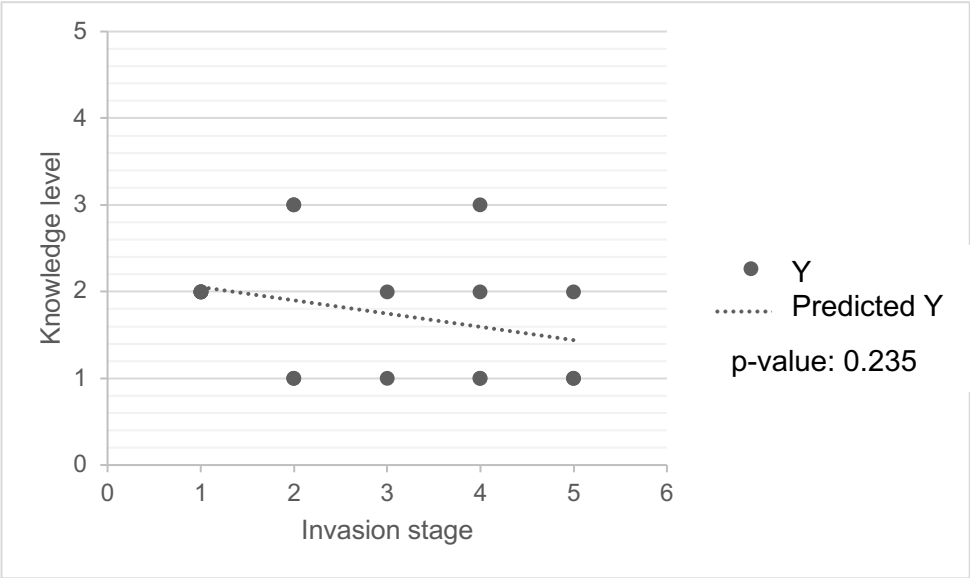

Figure 6 *The linear regression analysis that was conducted to evaluate the relationship between stakeholder's knowledge and invasion stage revealed no significant correlation.*

Stakeholder Interviews

The general response from the two respondents in the interviews that were conducted was positive. Both respondents stated that the framework felt well-structured and easy to follow and that a framework such as this, or similar, was very relevant and provides a good overall picture of what type of management can be implemented. However, respondents also expressed that there were several challenges that had to be overcome in order to implement the framework. A few of the challenges mentioned were that national authorities had to reevaluate access to the Pacific oysters (ownership) and risk of further increasing the dispersal of the species. Another problem that was mentioned was how conflicts can arise between areas when some, depending on invasion stage, are allowed to profit commercially from the oysters while others are requested to eradicate them. Answers for were responsibility of implementation should lie were similar as both interviewees stated that it should lie with SWAM (Swedish Agency for Marine and Water Management) and that county administrative boards should work regionally with implementing regulations decided by SWAM. Additional thoughts mentioned by the respondents were that in order to make the framework more applicable for municipalities in Sweden, it should be translated to Swedish, references included in the model were also suggested to be removed to make it easier to follow. A summary of the interview can be found in Appendix 4.

Discussion

In this study, several objectives and sub-objectives suitable for management of Pacific oysters as well as tools to achieve them were identified. The objectives and tools were found to differ between invasion stages. Consequently, a localized approach to management is suggested in accordance with previously published results (Herbert et al., 2012; Miljødirektoratet, 2016; Alves & Tidbury, 2022).

From objective to tool – with regard to invasion stage

Absence – Prevention, Prediction and Contingency planning

At localities where the species was absent, results suggested that one of the main management objectives is to prevent introduction (Hilliard, 2004; Mortensen et al., 2017; Geburzi & McCarthy, 2018). This can be achieved by monitoring and managing vectors of dispersal (Hillard 2004; Miljødirektoratet 2016; Hansen et al., 2023). Identification of vectors and assessment of ways to intercept and control them, is a first step to prevent an introduction. An important vector of dispersal for the Pacific oyster seems to be transportation with currents, mainly from Denmark (Faust et al., 2017), something that can prove hard to control. Other examples of local, and more easily controlled vectors, that also have to be evaluated, are passive transportation on boats and relays of left-over oysters (Dolmer et al., 2014).

Another important objective identified for "Absence" was to predict spread and future invasions. Tools to help achieve this are dispersal models (Laugen et al., 2015; Miljødirektoratet 2016; Mortensen et al., 2022; Hansen et al, 2023) and identification of areas suitable for oyster settlement (Dolmer et al., 2014; Miljødirektoratet 2016; Mortensen et al., 2022; Hansen et al., 2023). Dispersal models can help to predict dispersal and future settlement of larvae, which can aid in preventing and early discovery of an invasion. These models should, however, be further developed and incorporate more than currents and temperature, as this is not enough to predict spread (Mortensen et al., 2022). In order to increase accuracy of models, more parameters should also be considered, e.g., local conditions and when spawning occurs (Mortensen et al., 2022). Models should also incorporate future changes in temperature and salinity due to climate change (Alves & Tidbury, 2022; Hansen et al., 2023). Habitat suitability can also be assessed in different ways. Dolmer et al., (2014) conducted a risk assessment that concluded biogenic reefs and sub-littoral sediments in high energy areas to be at moderate to high risk of a Pacific oyster invasion, these are therefore habitats particularly important to identify and monitor. Spatial distribution modelling (SDM) (Bergström et al., 2021) and niche-modelling (Laugen et al., 2015) are techniques that can help identifying suitable habitats.

Another management objective identified was to resist establishment of Pacific oysters by increasing resilience of ecosystems (Morgan et al., 2021). One way of achieving this could be by approaching both national and internationals goals

regarding ocean health and biodiversity preservation. This could be done e.g., by strengthening or restoring populations of native bivalves and other important species (Morgan et al., 2021). Herbert et al. (2012) propose that increasing populations of native bivalves can help with filtering out *M. gigas* larvae from the water column and therefore decrease the risk of an invasion. Another tool to help maintain healthy ecosystems is continuous monitoring of diseases and pathogens, especially those associated with the Pacific oysters (Sundet et al., 2016; Nielsen et al., 2022).

Education and public awareness regarding the species, consequences of introduction and vectors of dispersal can also be important tools in helping to prevent introduction as well as to help with early detection (Wrange, 2008; Miljødirektoratet, 2016; Hansen et al. 2023). Information can be located at marinas, in recreational areas or online at municipalities or national authorities' websites (Miljødirektoratet, 2016).

Moreover, results suggest that before an invasion ("Absence"), contingency planning should take place (Hilliard, 2004; Miljødirektoratet, 2016), and risk assessments should be carried out (Miljødirektoratet, 2016) to understand potential consequences of an introduction and how effects can be minimized. An action plan for early eradication in case of invasion should be developed (Hilliard, 2004; Miljødirektoratet, 2016). The action plan should contain decisions on who should be responsible for coordinating and performing eradication, as well as what techniques should be applied (Hilliard, 2004).

Presence – Early detection, Eradication and Confinement

Monitoring was identified as a tool for early detection. If an invasion is discovered during early stages ("Presence"), eradication of the entire area can be feasible (Hilliard, 2004; Morgan et al., 2021). If an invasion is discovered, the previously developed action plan for early eradication should be implemented as soon as possible. There are several potential techniques for removal of oysters, with various CPUE (Cost Per Unit Effort), degree of destruction and effectiveness. Before any sort of culling (harvest) takes place, the goal should be to complete an environmental impact assessment, to make sure that native species and habitats will not be damaged in the process (Herbert et al., 2012; Miljødirektoratet 2016; Morgan et al., 2021). Mapping of populations should be carried out to identify where oysters are located and thereby where culling should take place (Miljødirektoratet, 2016). Citizen science can be used for mapping of oyster occurrences (Miljødirektoratet, 2016).

When an invasion has been discovered and is still in early stages ("Presence"), another management objective is to prevent further establishment. This can mainly be done by monitoring and managing vectors of dispersal and through education and public awareness, in the same way as during "Absence". It will also be important to

identify site connectivity to get further direction on what type of management should be implemented. Source populations contribute to further spread, while sink populations receive larvae that settle. Both are important to control to prevent further spread and to keep population densities low and avoid negative effects associated to e.g., reef formations (Miljødirektoratet 2016; Mortensen et al., 2022). In particular, source populations are important to manage (Dahl & Naustvoll, 2018) as a large number of the oysters in an area seems be located at a few, high density, sites that contribute most to further spread and establishment (Bergström et al.).

Survival and Reproduction – Control and Confinement

When an invasion has moved on from "Presence" and into either "Survival" or "Reproduction", eradication will not be feasible (Mortensen et al., 2019; Morgan et al., 2021; Mortensen et al., 2022; Hansen et al., 2023; Strand et al., 2023), but management can focus on control or possibly functional eradication (Hilliard 2004; Strand et al., 2023). Control can be carried out by limiting the size of non-eradicable populations, either at specific locations or entire areas (Christensen & Elmedal, 2007; Dolmer et al., 2014; Miljødirektoratet, 2016; Morgan et al., 2021; Mortensen et al., 2022). Like previously mentioned, mapping can help with identifying where culling should take place.

Another tool identified was management harvest. Management harvest can be applied through several methods, e.g., hand-picking (Bodvin et al., 2014; Miljødirektoratet, 2016; Cobacho et al., 2020; Morgan et al., 2021; Hansen et al., 2023) performed by both public volunteers (Guy and Roberts, 2010; Herbert et al., 2012; Morgan et al., 2021) or trained professionals. Harvest becomes harder and more destructive when oysters have formed reef structures (Nielsen et al., 2022). Such structures can be targeted using floating excavators (Nielsen et al., 2022) although this technique, and most mechanical removal techniques, i.e., dredging and diggers (Herbert et al. 2012; Morgan et al., 2021; Nielsen et al., 2022; Hansen et al., 2023) cause significant seabed disturbance. In general, harvest should be carried out along the entirety of a shoreline and should be repeated, preferably annually (Cobacho et al., 2020; Morgan et al., 2021).

Another way to control non-eradicable populations and prevent further establishment is to allow free fishing (Miljødirektoratet, 2016; Sundet & Hoel, 2016). This can permit for both recreational handpicking (Herbert et al., 2012), harvest for private use (Dahl & Naustvoll, 2018), harvest by local fisheries (Miljødirektoratet, 2016) and management related harvest (Miljødirektoratet, 2016). Providing incitements or having authorities (or equal) pay for food safety checks, perhaps in certain areas, can be a way to encourage utilization of this (Christensen & Elmedal, 2007; Herbert et al., 2012; Hansen et al., 2023).

In the same way as for "Presence", limiting spread and preventing further establishment was identified as management objectives for "Survival" and "Reproduction" (Hillard, 2004; Geburzi & McCarthy, 2018). Identifying sink and source populations as well as monitoring development of population structure and preventing populations from moving into the "Established" stage is of interest (Dolmer et al., 2014; Dahl & Naustvoll, 2018).

Established – Mitigation and Confinement

When an invasion has moved on to "Established", eradication attempts are futile, and one of the main management objectives will therefore be mitigation of negative effects (Hilliard, 2004; Geburzi & McCarthy, 2018). A risk assessment can help identify what negative effects an establishment of the invasive species may cause, as exemplified for Pacific oysters in Scandinavia by Mortensen et al., (2017) and depending on the specific area, different effects will be more highly prioritized to mitigate (Mortensen et al., 2022). Results suggests that management tools during the "Established" stage should be a combination of management harvest and commercial harvest (Bodvin et al., 2007; Dolmer et al., 2014; Sundet & Hoel, 2016; Miljødirektoratet, 2016; Giakoumi et al., 2019; Mortensen et al., 2019; Mortensen et al., 2022). Moreover, a market-based approach is suggested, with establishment of commercial fisheries that align with management objectives, which can be a feasible way forward to achieve an efficient management (Bodvin et al., 2007; Dolmer et al., 2014; Sundet & Hoel, 2016; Miljødirektoratet, 2016; Giakoumi et al., 2019; Mortensen et al., 2019; Mortensen et al., 2022). Additionally, preventing establishment in high value or sensitive areas (Bodvin et al., 2014; Miljødirektoratet, 2016; Dahl & Naustvoll, 2018; Mortensen et al., 2022; Hansen et al., 2023) by continued monitoring of spread and densities will be important.

Prerequisites for commercial harvest is, however, access to the resource (Mortensen et al., 2019), established food safety procedures, possibility of live-storage, establishment of markets for all shapes and size of oysters and further development of harvest methods suitable for large-scale harvest (Nielsen et al., 2022). Today in Sweden, the oysters belong to the landowner and there is no differentiation between the native flat oysters and the invasive Pacific oysters in the legislation. This means that in order to pick Pacific oysters, permission from the landowner is needed (Havs- och Vattenmyndigheten, 2015). There are also minimum size regulations for oysters, making management less efficient as only large oysters (>6 cm) can be picked. This regulation is, however, currently under revision to only apply to the native flat oyster (Havs- och Vattenmyndigheten, 2023) which could facilitate management efforts. Moreover, once harvested, it is desirable that all sizes of oysters and the entire oyster can be utilized after management harvest where oysters of different shapes and sizes are obtained. There are several potential areas of use for oysters, such as

construction materials, agriculture fertilizer (Linder, 2022) and plastic production (Morgan et al., 2021). There is also potential to develop tourism around the species, where harvest is combined with "eating your own oysters" (Christensen & Elmedal, 2007; Mortensen et al., 2022; Hansen et al., 2023). Some of these activities, e.g., commercial harvest at small scale and tourism, is already a reality in Sweden.

Besides commercial activities, a few alternative management tools are under development such as choking the oysters by covering them with sand or gravel (Hansen et al., 2023) or starving the oysters through competition with other filter feeding species by covering the oyster with e.g., blue mussels (Hansen et el., 2023). The efficiency of such methods remains, however, to be confirmed.

Framework implementation

To implement a dynamic management approach is, however, not without challenges. One issue that could arise with this type of management model, were objectives are dependent on invasion stage, is potential conflicts between municipalities. Commercial harvest may be used as a management tool in areas where the species is “Established”, which means that the oysters becomes a source of income for people in such areas. Meanwhile in other areas, where the species is in early stages of invasion, such as “Presence”, one of the main management objectives will be eradication of all oysters. An issue of unfairness could come to light as the species will be treated as a pest for some while others profit from it, a concern that also was mentioned during interviews with one of the stakeholders.

Another challenge is the substantial knowledge gap regarding management of Pacific oysters observed at municipalities. It is reasonable to think that also other stakeholder groups may display a similar knowledge gap. If prerequisites for management are met and a framework like this thesis presents can be applied, it is clear that most municipalities require guidance and support for implementation.

Based on the interviews, a few other aspects, were suggested to make implementation of the suggested framework in Sweden easier. Examples of suggestions includes translation of the framework into Swedish and simplification by elimination of references. The framework could also be further developed and improved by reviewing management options of other invasive species to provide even more objectives and tools that could help improve management. It could also be applied to other species, in order to identify knowledge gaps as well as to make it more generally applicable. For future reference, different methods for culling (harvest) should be investigated to find the least harmful, as well as most cost-effective, methods. Integration of practical management techniques into the framework may enhance the applicability of the framework for the stakeholders.

Conclusions

As results suggests, management objectives and management tools differ depending on invasion stage, indicating that management of the Pacific oyster along the Swedish west coast should be adapted to local conditions for more effective management. Several of the papers analyzed in the literature review suggested that a regional and localized approach to management of the Pacific oyster may be the most effective, and that management should be adapted to the stage of invasion. It is clear that stakeholder knowledge level regarding management of the Pacific oyster is insufficient, and that clear guidelines are needed for successful implementation of the developed framework. Several decisions must be made on national level for management to be possible, e.g., enable access to the oyster, implementation of innovative food safety protocols, and development of markets for new, untraditional, oyster products. For successful implementation, the framework should also be further connected to methods e.g., for culling.

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Appendices

Appendix 1 – Paper Quality Review

Note: (Y) = Yes, (N) = No, (U) = Unclear

Paper reference no.	1	2	3	4	5	6	7	8	9	10
Is the purpose of the paper clearly described and relevant for the project?	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y
Is the context clearly described?	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y
Is the collection of data clearly described?	Y	Y	U	Y	U	Y	U	Y	Y	Y
Is the analysis of the data logic and clearly described?	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y
Is the result of the analysis logic and clearly described?	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y
Is there anything missing?	N	N	U	N	U	N	N	N	N	N
Paper reference no.	**11**	**12**	**13**	**14**	**15**	**16**	**17**	**18**	**19**	**20**
Is the purpose of the paper clearly described and relevant for the project?	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y
Is the context clearly described?	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y
Is the collection of data clearly described?	N	N	N	Y	Y	Y	Y	Y	N	Y
Is the analysis of the data clearly described?	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y
Is the result of the analysis clearly described?	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y
Is there anything missing?	N	N	N	N	N	N	N	N	N	N
Paper reference no.	**21**	**22**	**23**	**24**	**25**	**26**	**27**			
Is the purpose of the paper clearly described and relevant for the project?	Y	Y	Y	Y	Y	Y	Y			
Is the context clearly described?	Y	Y	Y	Y	Y	Y	Y			
Is the collection of data clearly described?	Y	Y	Y	Y	Y	Y	U			
Is the analysis of the data logic and clearly described?	Y	Y	Y	Y	Y	Y	Y			
Is the result of the analysis logic and clearly described?	Y	Y	Y	Y	Y	Y	Y			
Is there anything missing?	N	N	N	N	N	N	U			

Appendix 2 – Summary of Papers Used in Literature Review

Ref. No.	Author(s)	Titel	Year, Publisher, Volume, Page(s)	Subject
1	Bergström et al.	Identifying high-density areas of oysters using species distribution modeling: Lessons for conservation of the native Ostrea edulis and management of the invasive Magallana (Crassostrea) gigas in Sweden	2021, Ecology and Evolution, 10, 11, 5522-5532	Conservation and Management
2	Mortensen et al.	Stillehavsøsters i Norden: Datainnsamling og bestandsvurderinger som grunnlag for forvaltning og høstning av nordiske bestander av stillehavsøsters, Crassostrea gigas	2022, Nordisk Ministerråd, 504, - , 1-61	Management and Harvest
3	Dolmer et al.	The invasive Pacific oyster, Crassostrea gigas, in Scandinavia coastal waters : A risk assessment on the impact in different habitats and climate conditions	2014, Institute of Marine Research	Risk Assesment
4	Christensen et al.	Den invasive Stillehavsøsters, Crassostrea gigas, i Limfjorden - inddragelse af borgere og interessenter i forslag til en forvaltningsplan	2007,Danmarks Fiskeriundersøgelser. DFU rapport No. 170-07	Management
5	Mortensen et al.	Policy Brief: The Pacific oyster – a new Nordic food resource and a basis for tourism	2019, Nordiska ministerrådet, s. 18	Alternative uses
6	Linder.	En jämförelse av användningsområden och kemisk sammansättning av skal från blåmusslor och stillahavsostron	2022, Gothenburg University Library	Alternative uses
7	Sundet et al.	The Norwegian management of an introduced species: the Arctic red king crab fishery	2016, Marine Policy, 72, 278-284	Management
8	Wrange, Anna-Lisa	UNDERSÖKNING AV DET JAPANSKA JÄTTEOSTRONET (CRASSOSTREA GIGAS) LÄNGS DEN SVENSKA VÄSTKUSTEN 2007-2008	2008, Aqualiens, Göteborgs Universitet	Distribution

9	Widing Hansen et al.	Too late for regulatory management on Pacific oysters in European coastal waters?	2023, Journal of Sea Research, 191	Management
10	Bodvin et al.	Registrering av vekst og fortetning av stillehavsøsters (Crassostrea gigas) på 6 utvalgte lokaliteter: Årsrapport 2014	2014, Miljødirektoratet	Monitoring and Management
11	Strand et al.	Japanska ostron i svenska vatten – Främmande art som är här för att stanna	2014, Vattenbrukscentrum Väst, 2	Distribution and Impacts
12	Dahl et al.	Utredning av prioriterte områder for tiltak mot stillehavsøsters i Vestfold	2018, Rapport fra Havsforskningen, 22	Culling and Important areas
13	Bodvin et al.	FAGGRUNNLAG STILLEHAVSØSTERS (Crassostrea gigas)	2014, Havforskningen, 32	Management
14	Mortensen et al.	Høsting av stillehavsøsters	2019, TemaNord, 552	Harvest/Culling and Management
15	Herbert et al.	Ecological impacts of non-native Pacific oysters (Crassostrea gigas) and management measures for protected areas in Europe	2016, Biodivers Conserv 25, 2835–2865	Impacts and Management
16	Cobacho et al.	Impacts of shellfish reef management on the provision of ecosystem services resulting from climate change in the Dutch Wadden Sea	2020, Marine Policy, 119	Reef Management
17	Guy & Roberts	Can the spread of non-native oysters (Crassostrea gigas) at the early stages of population expansion be managed?	2010, Marine Pollution Bulletin, 60, 7, 1059-1064,	Management
18	Herbert et al.	The Pacific Oyster (Crassostrea gigas) in the UK: Economic, Legal and Environmental Issues Associated with its Cultivation, Wild Establishment and Exploitation.	2012, Shellfish Association of Great Britain	Impacts
19	Miljødirektoratet	Handlingsplan stillehavsøsters (Crassostrea gigas)	2016, Miljødirektoratet	Management
20	Nielsen et al.	Development of mitigation strategies for control of Pacific oysters in Danish coastal waters	2022, DTU Aqua-rapport, No. 414	Management
21	Strand et al.	Kunskapsunderlag för en enhetlig förvaltning av OSPAR-	2023, IVL Svenska Miljöinstitutet, Rapport C730, 67s.	Management

		listade Mytilus- och Ostrea-bankar Del 2 - Metoder för restaurering och skydd av Mytilus- och Ostrea-bankar		
22	Morgan et al.	Partnership led strategy to monitor and manage spread of Pacific oyster populations in south Devon and Cornwall	2021, Natural England Research Reports, NERR100	Management
23	Giakoumi et al.	Management priorities for marine invasive species	2019, Science of the Total Environment 688, 976–982	Management
24	Teixeira Alves et al.	Invasive non-native species management under climatic and anthropogenic pressure: application of a modelling framework	2022, Management of Biological Invasions 13(2): 259–273,	Management
25	Hilliard	BEST PRACTICE FOR THE MANAGEMENT OF INTRODUCED MARINE PESTS	2004, URS Australia Pty Ltd. For GISP	Management
26	Mortensen et al.	Effects of a bio-invasion of the Pacific oyster, Crassostrea gigas (Thunberg, 1793) in five shallow water habitats in Scandinavia	2017, Management of Biological Invasions, Vol 8	Management
27	Geburzi & McCarthy	How Do They Do It? – Understanding The Success of Marine Invasive Species	2018, YOUMARES 8 – Ocean Across Boundaries: Learning from each other, pp 109-124	Invasion Success

Appendix 3 – Framework

Invasion Stage	Management Objective	Sub-objective	Management tool	Additional information
Absence (Le Gall, 2022)	Prevent introduction (Hilliard, 2004; Mortensen et al., 2017; Geburzi & McCarthy, 2018)	Control and limit vectors of dispersal (Hillard 2004; Miljødirektoratet 2016; Hansen et al., 2023)	Identify and asses' vectors of dispersal (currents, boats, relaying) (Hillard 2004; Miljødirektoratet 2016; Hansen et al., 2023)	Increase knowledge about species and vectors of dispersal.
			Monitor and manage vectors of dispersal (Hillard 2004; Miljødirektoratet 2016; Hansen et al., 2023)	
		Predict spread and future invasion (Hansen et al., 2023)	Develop dispersal models (Miljødirektoratet 2016; Mortensen et al., 2022; Hansen et al, 2023)	Oceanographic models can help predict dispersal and future invasion. Increasing temperatures in light of climate change should be taken into account, as well as future changes in salinity (Laugen et al., 2015; Alves & Tidbury, 2022; Hansen et al., 2023).
			Identify areas suitable for oyster settlement. (Dolmer et al., 2014; Miljødirektoratet 2016; Bergström et al., 2021; Mortensen et al., 2022; Hansen et al., 2023)	Habitats that have been identified to be at moderate to high risk of invasion are biogenic reefs and sub-littoral sediments in high energy areas (Bergström et al., 2021). These areas can be identified through mapping and through modelling. Both habitat modelling, spatial distribution modelling (Bergström et al., 2021) and niche modelling (Laugen et al., 2015) are useful for identifying habitats. The result can be connected to already existing maps of recreational

				and protected areas. Clearing of abandoned debris attractive for settling (Morgan et al., 2021).
			Identify areas that could act as natural barriers to prevent dispersal (Miljødirektoratet, 2016)	
		Monitoring (Hilliard, 2004; Herbert et al., 2012; Dolmer et al, 2014; Nielsen et al., 2022; Hansen et al., 2023)	Monitor identified areas for early detection (Mortensen et al., 2017) (Nielsen et al., 2022).	Molecular methods can help identify all life stages. (Hansen et al., 2023)
			General monitoring of area for early detection (Mortensen et al., 2017) (Nielsen et al., 2022).	
		Education and public awareness (Wrange, 2008; Miljødirektoratet, 2016 Hansen et al. 2023)	Disperse information about the species: what it looks like, how it is dispersed, what consequences an invasion can have.	Information can be distributed through lectures, indicative material online, posters at recreational sites etc. Reporting of sightings should be encouraged. (Miljødirektoratet, 2016)
	Resist establishment (Morgan et al., 2021)	Minimize negative effects and stresses on ecosystems by reaching both national and international goals, such as Agenda 2030 and the High Seas Treaty.	Strengthen/restore populations of native bivalves and other important species (Morgan et al., 2021) in order to increase resilience.	Herbert et al. (2012) suggests that increasing populations of native bivalves can help with filtering out M. gigas larvae from the water column and therefore help in the prevention of an invasion.
			Monitoring of disease and pathogens associated with the invasive species (Sundet et al., 2016; Nielsen et al., 2022)	
	Contingency planning (Hilliard, 2004; Miljødirektoratet, 2016)		Risk assessment (Miljødirektoratet, 2016)	Can help understand potential consequences of an introduction and how they can be

				prevented and minimized
			Develop action plan for early eradication in case of invasion (Hilliard, 2004; Miljødirektoratet, 2016)	Decisions on who should be responsible for coordinating and performing management actions should be made, and how it should be performed (Hilliard, 2004).
	Contingency planning (Hilliard, 2004; Miljødirektoratet, 2016)		Risk assessment (Miljødirektoratet, 2016)	Can help understand potential consequences of an introduction and how they can be prevented and minimized
			Develop action plan for management of invasion (Hilliard, 2004; Miljødirektoratet, 2016)	If there is not already an action plan in place one should be developed. Decisions on who should be responsible for coordinating and performing management actions should be made, and how it should be performed (Hilliard, 2004).
Presence (no signs of recruitment), (Le Gall, 2022)	Early detection (Mortensen et al., 2017; Geburzi & McCarthy, 2018; Nielsen et al., 2022; Hansen et al., 2023).	Monitoring (Hilliard, 2004; Herbert et al., 2012; Dolmer et al, 2014; Nielsen et al., 2022; Hansen et al., 2023)	Monitor area for early detection (Mortensen et al., 2017) (Nielsen et al., 2022).	Molecular methods can help identify all life stages.
			Identify habitats suitable for oyster settlement (Dolmer et al., 2014; Miljødirektoratet 2016; Mortensen et al., 2022; Hansen et al., 2023)	Habitats that have been identified to be at moderate to high risk of invasion are biogenic reefs and sub-littoral sediments in high energy areas (Bergström et al., 2021). These areas can be identified through mapping and through modelling. Both habitat modelling, spatial distribution modelling (Bergström et al., 2021) and niche modelling (Laugen et al., 2015) are useful

				for identifying habitats. The result can be connected to already existing maps of recreational and protected areas. Clearing of abandoned debris attractive for settling (Morgan et al., 2021).
			Monitor identified areas for early detection (Mortensen et al., 2017) (Nielsen et al., 2022).	
	Early eradication (Hilliard, 2004; Geburzi & McCarthy, 2018; Morgan et al., 2021)	Eradication of oysters in the entire area (Hilliard, 2004; Morgan et al., 2021)	Environmental Impact Assessment (Herbert et al., 2012; Miljødirektoratet 2016; Morgan et al., 2021)	Before activities of eradication or culling takes place an Environmental Impact Assessment should be undertaken to make sure that native species and habitats won´t be compromised.
			Implement action plan for early eradication (Hilliard, 2004; Miljødirektoratet, 2016)	There are several ways to go about when implementing management harvest. It can be carried out by volunteers or professionals, through hand picking or mechanical removal. Culling should be repeated yearly for optimal effective.
			Mapping (Miljødirektoratet, 2016; Mortensen et al., 2019; Mortensen et al., 2022).	Mapping of populations should be carried out to identify where oysters are located and thereby also where culling should take place (Miljødirektoratet, 2016). Populations of commercial value as well as populations of native bivalves should be noted (Mortensen et al., 2019; Mortensen et al., 2022). Citizen

				science can be applied for mapping (Miljødirektoratet, 2016).
	Confinement (Hilliard, 2004; Geburzi & McCarthy, 2018)	Prevent further establishment (Hilliard, 2004; Geburzi & McCarthy, 2018)	Identify site connectivity (Miljødirektoratet 2016; Mortensen et al., 2022).	It is important to identify the nature of populations to get further direction on what type of management should be implemented. Source populations contribute to further spread of larvae, while sink populations receive larvae that settle. Both are important to control, to prevent further spread and to keep populations densities low and prevent reef formation (Miljødirektoratet 2016; Mortensen et al., 2022).
			Monitor and manage vectors of dispersal (Hillard 2004; Miljødirektoratet 2016; Hansen et al., 2023)	If vectors of dispersals are not known it is important to identify and assess them (currents, boats, relaying) (Hillard 2004; Miljødirektoratet 2016; Hansen et al., 2023) in order to be able to manage them.
			Education and public awareness (Wrange, 2008; Miljødirektoratet, 2016 Hansen et al. 2023)	Disperse information about the species: what it looks like, how it is dispersed, what consequences an invasion can have.
	Resist further establishment (Morgan et al., 2021)	Minimize negative effects and stresses on ecosystems by reaching both national and international goals, such as Agenda 2030 and the High Seas Treaty.	Strengthen/restore populations of native bivalves and other important species (Morgan et al., 2021) in order to increase resilience.	Herbert et al. (2012) suggests that increasing populations of native bivalves can help with filtering out M. gigas larvae from the water column and therefore help in the prevention of an invasion.

Survival (signs of recruitment) and **Reproduction** (requirements for temperature and salinity met, local recruitment occurring). Increasing occurrences and densities of oysters from survival to reproduction (Le Gall, 2022)			Monitoring of disease and pathogens associated with the invasive species (Sundet et al., 2016; Nielsen et al., 2022)	
	Contingency planning (Hilliard, 2004; Miljødirektoratet, 2016)		Risk assessment (Miljødirektoratet, 2016)	Can help understand potential consequences of an introduction and how they can be prevented and minimized
			Develop action plan for management of invasion (Hilliard, 2004; Miljødirektoratet, 2016)	If there is not already an action plan in place one should be developed. Decisions on who should be responsible for coordinating and performing management actions should be made, and how it should be performed (Hilliard, 2004).
	Control / Functional Eradication (Hilliard 2004; Strand et al., 2023)	Limit size of non-eradicable populations at specific locations or entire area (Christensen & Elmedal, 2007; Dolmer et al., 2014; Miljødirektoratet, 2016; Morgan et al., 2021; Mortensen et al., 2022)	Environmental Impact Assessment (Herbert et al., 2012; Miljødirektoratet 2016; Morgan et al., 2021)	Before activities of eradication or culling takes place an Environmental Impact Assessment should be undertaken to make sure that native species and habitats won't be compromised.
			Mapping (Miljødirektoratet, 2016; Mortensen et al., 2019; Mortensen et al., 2022).	Mapping of populations should be carried out to identify where oysters are located and thereby also where culling should take place (Miljødirektoratet, 2016) Populations of commercial value as well as populations of native bivalves should also be noted (Mortensen et al., 2019; Mortensen et al., 2022). Citizen science can be applied for mapping.

			Management harvest (Bodvin et al., 2007; Dolmer et al., 2014; Sundet et al., 2016; Miljødirektoratet, 2016; Giakoumi et al., 2019; Mortensen et al., 2019; Mortensen et al., 2022).	There are several ways to go about when implementing management harvest. It can be carried out by volunteers or professionals, through hand picking or mechanical removal. Culling should be repeated yearly for optimal effective.
			Target high density populations (Dahl & Naustvoll, 2018; Bergström et al., 2021)	Currently, in high-density areas, there seems to be a few populations with high densities that contribute the most to further dispersal etc (Bergström et al., 2021). By targeting these populations management would be more effective. It would also be of interest to investigate if this is the case in low-density areas.
	Confinement (Hilliard, 2004; Geburzi & McCarthy, 2018)	Limit spread of non-eradicable populations (Hillard, 2004; Geburzi & McCarthy, 2018)	Open access to stocks (Miljødirektoratet, 2016; Sundet et al., 2016)	Open access to populations can help with management as a way of controlling size and further spread of the species (Miljødirektoratet, 2016; Sundet et al., 2016). Bounty or other sort of incitement by authorities on eradication can help to achieve management goals (Christensen & Elmedal, 2007; Herbert et al., 2012; Hansen et al., 2023). Open access can allow for both commercial and non-commercial harvest. Cullings are most effective when repeated over time (Cobacho et al.,

				2020; Morgan et al., 2021).
			Monitor and manage vectors of dispersal (Hillard 2004; Miljødirektoratet 2016; Hansen et al., 2023)	If vectors of dispersals are not known it is important to identify and assess them (currents, boats, relaying) (Hillard 2004; Miljødirektoratet 2016; Hansen et al., 2023) in order to be able to manage them.
		Prevent further establishment (Hilliard, 2004; Geburzi & McCarthy, 2018)	Identify site connectivity (Miljødirektoratet 2016; Mortensen et al., 2022).	It is important to identify the nature of populations to get further direction on what type of management should be implemented. Source populations contribute to further spread of larvae, while sink populations receive larvae that settle. Both are important to control, to prevent further spread and to keep populations densities low and prevent reef formation (Miljødirektoratet 2016; Mortensen et al., 2022).
			Monitor development of populations (Dolmer et al., 2014; Dahl & Naustvoll, 2018)	Populations should be monitored to prevent them from moving into the "established stage"
		Prevent establishment of populations in high value/sensitive areas (Bodvin et al., 2014; Miljødirektoratet, 2016; Dahl & Naustvoll, 2018; Mortensen et al., 2022; Hansen et al., 2023)	Continued monitoring of spread and densities (Hilliard, 2004; Herbert et al., 2012; Dolmer et al, 2014; Nielsen et al., 2022; Hansen et al., 2023)	Recreational areas, nature reserves and areas with important and sensitive species or habitat types are considered to be extra important to protect. It is therefore crucial to prevent establishment of invasive oyster populations that cause a significant

				change in ecosystem function.
	Resist further establishment (Morgan et al., 2021)	Minimize negative effects and stresses on ecosystems by reaching both national and international goals, such as Agenda 2030 and the High Seas Treaty.	Strengthen/restore populations of native bivalves and other important species (Morgan et al., 2021) in order to increase resilience.	Herbert et al. (2012) suggests that increasing populations of native bivalves can help with filtering out M. gigas larvae from the water column and therefore help in the prevention of an invasion.
Established (population size and structure) (Le Gall, 2022)			Monitoring of disease and pathogens associated with the species (Sundet et al., 2016; Nielsen et al., 2022)	
	Contingency planning (Hilliard, 2004; Miljødirektoratet, 2016)		Risk assessment (Miljødirektoratet, 2016)	Can help understand potential consequences of an introduction and how they can be prevented and minimized
			Develop action plan for management of invasion (Hilliard, 2004; Miljødirektoratet, 2016)	If there is not already an action plan in place one should be developed. Decisions on who should be responsible for coordinating and performing management actions should be made, and how it should be performed (Hilliard, 2004).
	Mitigation (Hilliard, 2004; Geburzi & McCarthy, 2018)	Risk assessment (Miljødirektoratet, 2016)	Prioritize what effects to mitigate (Mortensen et al., 2022).	The risk assessment should identify what negative effects an establishment brings along, and depending on the specific area, different effects will be more highly prioritized to mitigate. Such as removing shells from beaches in recreational areas or protecting native bivalve populations (Mortensen et al., 2022).

		Management actions	Mapping (Miljødirektoratet, 2016; Mortensen et al., 2019; Mortensen et al., 2022).	Mapping of populations should be carried out to identify where oysters are located and thereby also where culling should take place (Miljødirektoratet, 2016) Populations of commercial value as well as populations of native bivalves should be noted (Mortensen et al., 2019; Mortensen et al., 2022). Citizen science can be applied for mapping.
			Environmental Impact Assessment (Herbert et al., 2012; Miljødirektoratet 2016; Morgan et al., 2021)	Before activities of eradication or culling takes place an Environmental Impact Assessment should be undertaken to make sure that native species and habitats won't be compromised.
			Management harvest (Bodvin et al., 2007; Dolmer et al., 2014; Sundet et al., 2016; Miljødirektoratet, 2016; Giakoumi et al., 2019; Mortensen et al., 2019; Mortensen et al., 2022).	There are several ways to go about when implementing management harvest. It can be carried out by volunteers or professionals, through hand picking or mechanical removal. Culling should be repeated yearly for optimal effective.
			Commercial harvest (Bodvin et al., 2007; Dolmer et al., 2014; Sundet et al., 2016; Miljødirektoratet, 2016; Giakoumi et al., 2019; Mortensen et al., 2019; Mortensen et al., 2022).	A market-based approach through establishment of commercial fisheries that align with management objectives could be feasible. Prerequisites for commercial harvest is access to the resource, guaranteed food safety, live-storage of species,

				establishment of market for all sizes of oysters, further development of harvest methods suitable for large-scale harvest. (Bodvin et al., 2007; Dolmer et al., 2014; Sundet et al., 2016; Miljødirektoratet, 2016; Giakoumi et al., 2019; Mortensen et al., 2019; Mortensen et al., 2022)
			Market development (Mortensen et al., 2022; Nielsen et al., 2022).	For harvest of oysters to align with management objectives it is desirable to make sure that all types of oysters and the entire oyster can be utilized. There are several potential areas of use for oysters, such as construction materials, agriculture fertilizer (Linder, 2022) and plastic production (Morgan et al., 2021). There is also potential to develop a tourism around the species, where harvest is combined with "eating your own oysters" (Christensen & Elmedal, 2007; Mortensen et al., 2022; Hansen et al., 2023).
			Alternative tools	There are currently a few potential tools under development such as choking or starving the Pacific oysters by covering them with sand or gravel (Hansen et al., 2023) or starving the oysters through competition with other filter feeding species. This would

				be done by covering the Pacific oyster with one of its biggest competitors, the blue mussel (Hansen et el., 2023).
			Continued research (Hilliard, 2004, Herbert et al., 2012; Miljødirektoratet, 2016; Hansen et al., 2023).	Into ways of managing populations, development of tools for culling, consequences of invasion etc.
	Confinement (Hilliard, 2004; Geburzi & McCarthy, 2018)	Limit spread of non-eradicable populations (Hillard, 2004; Geburzi & McCarthy, 2018)	Monitor and manage vectors of dispersal (Hillard 2004; Miljødirektoratet 2016; Hansen et al., 2023)	If vectors of dispersals are not known it is important to identify and assess them (currents, boats, relaying) (Hillard 2004; Miljødirektoratet 2016; Hansen et al., 2023) in order to be able to manage them.
		Prevent further establishment (Hilliard, 2004; Geburzi & McCarthy, 2018)	Identify site connectivity (Miljødirektoratet 2016; Mortensen et al., 2022).	It is important to identify the nature of populations to get further direction on what type of management should be implemented. Source populations contribute to further spread of larvae, while sink populations receive larvae that settle. Both are important to control, to prevent further spread and to keep populations densities low and prevent reef formation (Miljødirektoratet 2016; Mortensen et al., 2022).
		Prevent establishment of populations in high value/sensitive areas (Bodvin et al., 2014; Miljødirektoratet, 2016; Dahl &	Continued monitoring of spread and densities (Hilliard, 2004; Herbert et al., 2012; Dolmer et al, 2014; Nielsen et al., 2022;	Recreational areas, nature reserves and areas with important and sensitive species or habitat types are considered to be extra important to protect. It is therefore crucial to

		Naustvoll, 2018; Mortensen et al., 2022; Hansen et al., 2023).	Hansen et al., 2023).	prevent establishment of invasive oyster populations that cause a significant change in ecosystem function.
	Resist further establishment (Morgan et al., 2021)	Minimize negative effects and stresses on ecosystems by reaching both national and international goals, such as Agenda 2030 and the High Seas Treaty.	Strengthen/restore populations of native bivalves and other important species (Morgan et al., 2021) in order to increase resilience.	Herbert et al. (2012) suggests that increasing populations of native bivalves can help with filtering out M. gigas larvae from the water column and therefore help in the prevention of an invasion.
			Monitoring of disease and pathogens associated with the species (Sundet et al., 2016; Nielsen et al., 2022)	

Appendix 4 – Interviews with Stakeholders

1. First thoughts regarding the framework?

A: Nice to have something well-structured that gives clear guidance for what management options

are available. Makes it easier to manage.

B: Good matrix for management. Well arranged. It is hard to know how to deal with an invasive species, since it is considered something you want to get rid of.

2**. Do you think this, or similar, frameworks are needed for oysters or other invasive species?**

A: Feels very relevant with such a framework. Above all I think it is important to focus on areas where the species is not established yet. Focus should also be put on protected areas. Have not had any mandate to manage the species before but we have been working preventively with spreading information (e.g., about what the species looks like, so the wrong oysters are not removed.

B: Yes, good that it builds on biological data from invasion stages.

3. What do think will be the biggest challenges for implementation of the framework?

A: It is a commercially important species; it will be difficult to change the law to exploit it. Changing the law can remove income for landowners. Can be sensitive with open access and landowner having to see people take something from their land. Regulation where authorities can introduce measures could be a simpler alternative. Permits for cultivation will also be a challenge.

B: Several decisions have to be made at national and regional level. Authorities at a higher level will have to make decisions about weather commercial use and cultivation (management as a resource) will be allowed. Potential risk that cultivation etc. may contribute to continued spread. Potential conflicts when some can make money from it while others have to fight it. Maybe the oysters should become more “common-law” or make it the responsibility of the landowner, more like on land.

4. Who do you think should be responsible for implementing the framework?

A: The main responsibility for guidance and ensuring that regulations/frameworks are in place must lie with SWAM, while county administrative boards are given responsibility for working with it regionally.

B: With SWAM.

5. What role do you think county administrative boards should play in implementation of the framework?

A: They should work with it regionally and with legislation that is already in place.

B: The county administrative board must adhere to regulation issued by SWAM regarding what can be done at what stage.

6. What prerequisites are needed, in your opinion, for implementation of the framework to be successful?

A: DynamO's work is important to know which area should be managed and how. Important to incorporate the management of the oyster into current management plan/operations. Focus on protected areas and introduce management of Pacific oysters into management agreements.

B: There are conflicts that need to be resolved and overall decisions that need to be made beforehand, e.g., about commercial exploitation. Hard to see how commercial exploitation could align with management.

7. Does the management objectives feel applicable and relevant?

A: Yes. Good to have a plan for each species, have not had any mandate to handle the oysters before. The framework will be applicable to other species as well.

B: Yes.

8. Does the management tools feel applicable and relevant?

A: Yes, seems easy to follow as well.

B: Some things feel repetitive, such as general monitoring and monitoring of areas that have been identified as vulnerable, it might be good to combine them to make it work better in practice.

9. Is there anything you feel is missing from the framework?

A: Yes, methods for culling/harvest.

B: No, nothing that I can think of right now.

10. Is there anything in the framework that feels redundant to you?

A: I don't know, need to have a closer look.

B: No, just that there are some overlaps, such as the monitoring. Can possible be shortened to become even more practically applicable.

11. Does the framework feel concrete enough?

A: Yes.

B: Yes, but somethings can be merged.

12. Other thoughts?

A: It might be good to incorporate costs into the model. It is important to set goals that can be reached with the resources available. For successful implementation by Swedish municipalities and counties it should be translate into Swedish, and references etc. must be removed to make it even clearer.

B: It is well structured and can be applicable to other species as well. Better national management of the species is required.