Johannes Müller

Sparus aurata escapes from offshore fish farms around Madeira

UNIVERSIDADE DO ALGARVE

Faculdade de Ciências e Tecnologia

2019

Johannes Müller

Sparus aurata escapes from offshore fish farms around Madeira

Mestrado em Biologia Marinha

Supervisors:
Dr. Carlos Andrade
Co-supervisor:
Dr. Jorge Gonçalves

UNIVERSIDADE DO ALGARVE

Faculdade de Ciências e Tecnologia

2019

Statement of authorship and copyright

Declaração de autoria de trabalho

Sparus aurata escapes from offshore fish farms around Madeira

I hereby declare to be the author of this work, which is original and unpublished. Authors and used literature are properly cited and all works are listed in a list of references included at the end of this work. The University of Algarve reserves the right for itself to archive, reproduce and publish this work in accordance with the code of copyright and related rights; regardless of the medium used and to disseminate it through scientific and technical repositories. To allow the copy and distribution of this work purely for educational and research purposes, and not for commercial use, provided that the respective author and publisher are given due credit.

Declaro ser o(a) autor(a) deste trabalho, que é original e inédito. Autores e trabalhos consultados estão devidamente citados no texto e constam da listagem de referências incluída. A Universidade do Algarve reserva para si o direito, em conformidade com o disposto no Código do Direito de Autor e dos Direitos Conexos, de arquivar, reproduzir e publicar a obra, independentemente do meio utilizado, bem como de a divulgar através de repositórios científicos e de admitir a sua cópia e distribuição para fins meramente educacionais ou de investigação e não comerciais, conquanto seja dado o devido crédito ao autor e editor respetivos.

X

Johannes Müller, Faro, 30/09/2019

Acknowledgements

First and foremost, I am grateful for getting the opportunity of this project on the beautiful Island Madeira and the all the help provided by my supervisor Dr Carlos Andrade and Co-supervisor Dr Jorge Gonçalves.

I am also thankful for the help I received from the local farming facilities on Madeira including the farm staff and their cooperation in this project.

To the Portuguese Institute for Sea and Atmosphere for providing valuable data on sea conditions, which was vital for this work.

To Mariana and all the colleges at the Mariculture Centre of Calheta, who provided help during my work in Madeira.

To Marcio who helped me with the translation of the abstract.

To all the amazing people I met during my stay on Madeira Island, who made it a memorable time.

To my friends in Faro from my Master course at the University of Algarve.

To Verena who was always there for me, Manuel, Robin, Luis and Pete who visited me during my stay on Madeira and everyone who managed to keep contact, despite my remote location.

Lastly, I am very thankful for all the support I got from my friends and family from home. Without you it would have been impossible to run this project.

Abstract

In Madeira, an archipelago situated in the North Eastern Atlantic, *Sparus aurata* was recorded in the wild shortly after the introduction of this species to offshore farming facilities in 1997. In this study, oceanographic and maintenance data of fish farms from Madeira was gathered to evaluate the most relevant factors behind the escapes of *Sparus aurata*. The community of fish associated with the farming facilities was analysed with the help of an underwater camera-system. Also, previously escaped specimens of *S. aurata* were caught in the wild, followed by stomach content analysis. Archive data from regular inspection dives from the Calheta offshore fish farm was analysed with corresponding data on sea conditions. Results point towards the relevance of extreme weather and sea conditions and related structural failure for fish escapes; a significant correlation was found between wave height and the amount of recorded net-damage at the fish farming facilities. However, certain damage was unlikely caused by structural failure and may be the result of predator attack or other causes. Notwithstanding the above, the abundance of top carnivorous species (e.g. *Seriola spp., Pomatomus saltatrix* and *Spyraena viridensis*) appeared to be low and an analysis of underwater footage revealed, that the most abundant species around the farm were *Trachinotus ovatus* and *Sardinella maderensis*. An examination of 38 escapee seabream caught in the harbour of Calheta indicated, that *S. aurata* preferably feed on fish and the diet appears to differ substantially from conspecifics within the native distribution range. All sampled animals were considered sexually immature, not providing evidence for the existence of a self-sustaining population of *S. aurata* in the wild. Future research is necessary to fully comprehend all relevant factors involved in the escapes of *S. aurata* from Madeiran fish farms and to further assess possible impacts of the species on the local ecosystem.

Keywords: Gilthead seabream, *Sparus aurata,* Escapees, Offshore aquaculture, Archive data, Madeira Island

Resumo

Recentemente, a aquacultura intensiva tem sido uma indústria em expansão no Mediterrâneo e no Atlântico Nordeste; e a dourada (*Sparus aurata)* sendo uma das espécies mais frequentemente produzidas. O arquipélago da Madeira, localizado a 32.75°N, 17°W, no Atlântico Nordeste é um dos locais onde esta espécie é cultivada. Apesar da dourada não ser nativa do local, esta é cultivada comercialmente em várias instalações de aquacultura "offshore" no Sul da ilha da Madeira. Pouco tempo depois do início da primeira exploração, em 1997, foram descobertos indivíduos selvagens de *S. aurata*. As atividades de cultivo foram consideradas como a fonte mais provável da ocorrência desta espécie nas águas do arquipélago, sendo que a fuga de indivíduos de aquacultura é um problema conhecido. Estes eventos de fuga estão ligados a uma variedade de riscos para o ecossistema onde ocorrem, desde a introdução de espécies não nativas, introdução de organismos patogénicos e até perdas económicas para os piscicultores. Estudos anteriores identificaram a importância de condições climatéricas extremas, e os danos estruturais que estas provocam, como sendo uma das principais causas de fuga de indivíduos, bem como, de danos provocados pelos próprios peixes às redes, ataques de predador e erros operacionais.

Este estudo representa uma primeira abordagem na investigação dos eventos recorrentes de fuga de *S. aurata* e alguns dos possíveis impactos da introdução desta espécie no arquipélago da Madeira. Os functioários das instalações de aquacultura inspecionam-nas regularmente por mergulho e visitam-nas diariamente para alimentar os peixes. Durante os mergulhos, as redes são inspeccionadas. Se algum dano for encontrado, a informação sobre o dano é registada, bem como, a informação acerca das condições do mar, presença de predadores e a quantidade de alimento que foi fornecida aos indivíduos de cultivo. Os registos de uma instalação de cultivo na Calheta foram analisados e relacionados com as condições do mar. Os dados relativos à ondulação (altura significativa e altura máxima da onda) foram fornecidos pelo IPMA (Instituto Português do Mar e Atmosfera). A análise dos dados indicou uma correlação positiva entre a altura da onda e o número de danos encontrados nas redes (com um R entre 0 e 0.344). Nas jaulas maiores, de 24 m de diâmetro, esta correlação foi geralmente significativa ($P< 0.05$), exceto jaula 10.

Durante um episódio de condições climatéricas extremas em Fevereiro de 2019, com ondas acima de 10m (com alturas máximas de 10.87m), seis das jaulas de cultivo na Ribeira Brava sofreram significativos danos estruturais. Este evento levou à libertação de mais de 1 000 000 de indivíduos de *S. aurata*, o que reforça o possível impacto de eventos de falhas estruturais por condições climatéricas. No entanto o elevado número de danos nas redes das jaulas da piscicultura da Calheta, em condições climatéricas calmas, mostra que estes eventos não são a única causa de fugas. É possível que estes danos tenham sido provocados por ataques de predadores, uma vez que a presença de espécies predatórios (tal como *Pomatomus saltatrix*) em redor das jaulas de cultivo é comum, em particular durante os meses de Verão. No entanto, fatores como danos estruturais ou outros parâmetros ambientais podem também estar envolvidos.

Em adição à análise dos dados históricos das instalações de cultivo, a comunidade de peixes associada às instalações de cultivo na Calheta também foi investigada. Entre Dezembro de 2018 e Abril de 2019, foram feitas um total de 19 visitas às instalações. Durante estas visitas, uma câmara subaquática montada numa vara de 5m foi usada para filmar as espécies de peixes associadas às instalações de cultivo. A aplicabilidade deste sistema de vídeo foi testada durante este estudo, resultando em 167Gb de conteúdo. Os dados foram tratados como registos de presença/ausência e permitiram a identificação de 6 espécies. Os resultados mostram uma riqueza específica S entre 2 e 4, e sugerem que as espécies mais comuns em redor das jaulas são *Trachinotus ovatus* and *Sardinella maderensis*, estando presentes em 100% dos vídeos recolhidos, provavelmente a alimentar-se de ração em excesso e excreções que são levadas para fora das jaulas. Em 21% dos vídeos, indivíduos de *Sphyraena viridensis* e *Balistes capriscus,* ambas espécies predatórias, estavam presentes. De acordo com empregados das instalações de cultivo, *B. capriscus* foram previamente observados a consumir indivíduos mortos nas jaulas e podem provocar parte dos danos às redes. O nosso estudo mostra que um sistema de câmara subaquática é uma ferramenta viável e útil para avaliar a comunidade de peixes associados a instalações de cultivo, apesar de ter algumas limitações.

O impacto de *S. aurata* num ecossistema fora dos limites de distribuição nativa da espécie estão, maioritariamente, por estudar. Apesar da presença desta espécie na Madeira ser conhecida há 20 anos, não temos conhecimento de algum trabalho para avaliar o impacto da espécie nos ecossistemas locais. Ao longo deste estudo, 38 indivíduos selvagens de *S. aurata* foram colhidos no porto da Calheta, usando equipamento de pesca recreacional.

Os peixes foram medidos, as gónadas inspecionados visualmente e avialado o conteúdo estomacal. Os indivíduos amostrados eram juvenis em fase de pré-maturação sexual e com um comprimento até à bifurcação da barbatana caudal entre os 15.5 e 27 cm (média de 21.75 ± 2.59cm) e pesos entre as 60.89g e 457.2g (media de 192.92 ± 78.28g). Os resultados não sugerem que exista um risco de existir uma população estável de *S. aurata* na madeira.

As análises de conteúdo estomacal mostram que os indivíduos selvagens de *S. aurata* se alimentam de uma variedade de presas, sendo que outros peixes constituíram 50.3% do peso do conteúdo ingerido. A ração comercial constituiu a segunda principal fonte de alimento, com 15.1% do peso do conteúdo estomacal . Estes resultados mostram a capacidade de *S. aurata* de se adaptar a novas fontes de alimento, uma vez que esta dieta difere substancialmente da dieta disponível na distribuição nativa da espécie e da dieta exclusiva de rações nas jaulas de cultura. A elevada abundância de peixe nos conteúdos estomacais dos indivíduos amostrados implica um possível risco para o ecossistema local. No enfanto não foi possível verificar se o peixe consumido tem origem em descartes junto ao local de sua captura ou se foi predado vivo pela dourada.

A cultura em “offshore” de peixe representa um desafio, uma vez que as condições climatéricas extremas representam um grande risco de fuga de indivíduos das instalações de cultivo. Um estudo do local, recorrendo a dados climatéricos, antes da construção de novas instalações pode ajudar a prevenir estes eventos. No entanto, existem outras possíveis causas de eventos de fuga que não estão totalmente identificadas. Para investigar potenciais riscos da libertação de *S. aurata* nas águas do arquipélago da Madeira, é necessário amostrar mais indivíduos selvagens e analisar os seus conteúdos estomacais, idealmente aplicando técnicas genéticas. Um estudo mais completo, usando métodos como o uso de câmaras subaquáticas remotas pode permitir a observação das estruturas de cultivo e de predadores, ajudando a perceber qual a sua importância em eventos de fuga. Pesquisas futuras são necessárias para compreender plenamente as razões para a fuga de *S. aurata* das fazendas de peixes Madeiranos e para entender o papel que a espécie desempenha na natureza. Estes poderiam ser de interesse económico para os agricultores de peixes e de uso para avaliar as implicações ecológicas de peixes escapados.

Contents

List of tables and figures

Tables

Figures

List of abbreviations, acronyms and symbols

Symbol/abbreviation	**Explanation**
%	Percent
t	Metric ton
°	Degree
N	North
S	South
E	East
W	West
km	Kilometers
m	Meters
cm	Centimeter
min	Minutes
R	Correlation coefficient
y	Year
SD	Standard deviation
S	Species richness index

Chapter 1 Introduction

In Western Europe, fish farming in fresh- and saltwater has been practiced since ancient times (Rana, 2005). At present, 69% of the 397 European fish stocks are affected by overfishing and many stocks suffered declines (Jackson et al., 2001; Froese et al., 2018). Therefore, fish farming now constitutes an important additional source of fresh seafood to western markets and represents a fast-growing global industry (Trujillo et al., 2012). In 2016, 47% of the total world fish production originated from aquaculture. According to FAO (2018), the total food fish production in Europe was 2,945,000t in 2016 and Norway the most important producing country with 1,326,000t. Aquaculture offers the benefit of providing fish for local and foreign markets combined with economic benefits. New technological developments have allowed for the expansion of farming facilities into offshore locations (Gentry et al., 2017). However, aquaculture in offshore farming facilities is connected to a range of risks and is therefore often criticized (Read & Fernandes, 2003).

Figure 1.1 Open cage offshore farming facility for *S. aurata* in Calheta, Madeira, Portugal

Offshore fish farms may affect the environment: The release of nutrients and chemicals (Wu, 1995) from farms in the form of faeces, food pellets, antibiotics and chemicals from the construction materials (i.e. stabilizers, pigments and antifoulants) (Cao et al., 2007) through aquaculture can lead to alterations in the benthic zone (Wu et al., 1994; Tomassetti et al., 2016). Farming facilities are known to attract wild fish (Dempster et al., 2002). Most notably, offshore farming facilities represent a permanent risk for the escape of fish (Dempster et al., 2007; Jackson et al., 2015; Thorvaldsen et al., 2015; Arechavala-Lopez et al., 2018a). A fish escape thereby refers to an individual fish, or a group of fish exiting the net cage (Arechavala-Lopez et al., 2018a). Losses due to fish escapement lead to significant financial damage for the farm owners, that was estimated to be as high as €42.8 million per year for gilthead seabream *Sparus aurata* and European seabass *Dicentrarchus labrax* (Jackson et al., 2015). Aside economic damage, the release of farmed fish also generates risks for the local environment. Escaped fish alter the genetic pool, which can lead to a decreased fitness in wild populations (McGinnity et al., 2003) and escapees may be involved in the distribution of parasites (Arechavala-Lopez et al., 2013) and bacteria possessing resistance for antibiotics (Austin, 1993). Moreover, escaped, non-native fish may interact with native species and compete with them for food (Declerck et al., 2002) or prey on them (Albins, 2013). Notwithstanding the above, a recent technical report integrating the concepts of Blue Growth and Marine Strategy Framework Directive on good environmental status for sustainable development has shown no significant environmental issues related to the finfish aquaculture activity in the Macaronesia Islands of Canaries and Madeira (Png-Gonzalez et al., 2019).

Situated in the subtropical North-eastern Atlantic Ocean (32.75°N, 17°W) off the coast of Marocco, Madeira Island is a popular destination for tourists (Oliveira, 2008). The waters around the island support local fisheries and are inhabited by a wide variety of marine life. Around the archipelagos of Madeira, Desertas and Selvagens there are five marine protected areas; some of them among the oldest marine reserves in Portugal (Friedlander et al., 2017). The gilthead seabream *S. aurata*, initially not native to Madeira Island, has first been recorded in 2000, shortly after farming of the species started in offshore open cage farming facilities in 1997; regarded as the most probable cause for the introduction of the species to Madeiran waters (Alves & Alves, 2002).

Figure 1.2 Geographical location of Madeira Island, retrieved and adapted from google.maps © 2019 Inst. Geogr. Nacional, Google

The gilthead seabream *Sparus aurata* belongs to the family of *Sparidae* and is common in the Mediterranean Sea and Atlantic, including several Islands (FAO, 2019). Here, the species inhabits sandy bottoms, seagrass beds and the surf zone up to a depth of approximately 150m (Bauchot & Hureau, 1990). In aquaculture, *S. aurata* accounted for a total production of 181,442 t in 2015 (FAO, 2016), produced mostly in the Mediterranean Sea, but also in the Atlantic archipelagos of the Canaries and Madeira. Despite the knowledge about the presence of *S. aurata* in the waters around Madeira Island, information about the causes of the occurring escape events and the possible influence of the species on the environment remains scarce.

Most farming activities of *S. aurata* take place within the native distribution range of the species. First studies targeting the possible influence of escapee *S. aurata* were conducted e.g. in the Messolonghi Lagoon, Greece (Dimitriou et al., 2007) and the Gulf of California (Balart et al., 2009). However, there appears to be a great knowledge gap. The presence of a formerly absent species implies risks such as the degradation of the host-environment, the break-down of the host community and the introduction of pathogens (Welcome, 1988) This problematic has gained global interest, as ecological impacts are often more serious and less predictable with non-native species (Edelist et al., 2013). To reduce the number of escapees from the steadily growing number of offshore faming facilities, it is urgent to understand the causes of escape events. Further it is relevant to analyse the possible influences of previously escaped animals on the local environment, so that management plans can be put in action, if necessary. This is even more relevant in an environment, such as Madeira, where the farmed species *S. aurata* is non-native.

This works aims to:

1. Identify the most relevant causes for seabream *S. aurata* escapes in Madeiran fish farms through the analysis of historical archive data;

2. Analyse the relevance of storms and rough sea conditions for the occurring net damage in the fish farming facilities with emphasis on wave and wind data;

3. Analyse the species community of wild fish and other animals around Madeira's farming facilities and the potential relevance for escape events;

4. Test the applicability of a newly constructed camera system for the evaluation of wild fish species associated with Madeira's fish farming facilities;

5. Gain a first insight into the population of previously escaped seabream *S. aurata* in the wild, including an analysis of the preferred diet;

6. Evaluate the size-structure and sexual maturation stage of escapee-seabream specimens to investigate the possible risk of a self-sustaining population in Madeira Island waters;

Chapter 2 Risk assessment of Madeiran fish farms through analysis of historical archive data

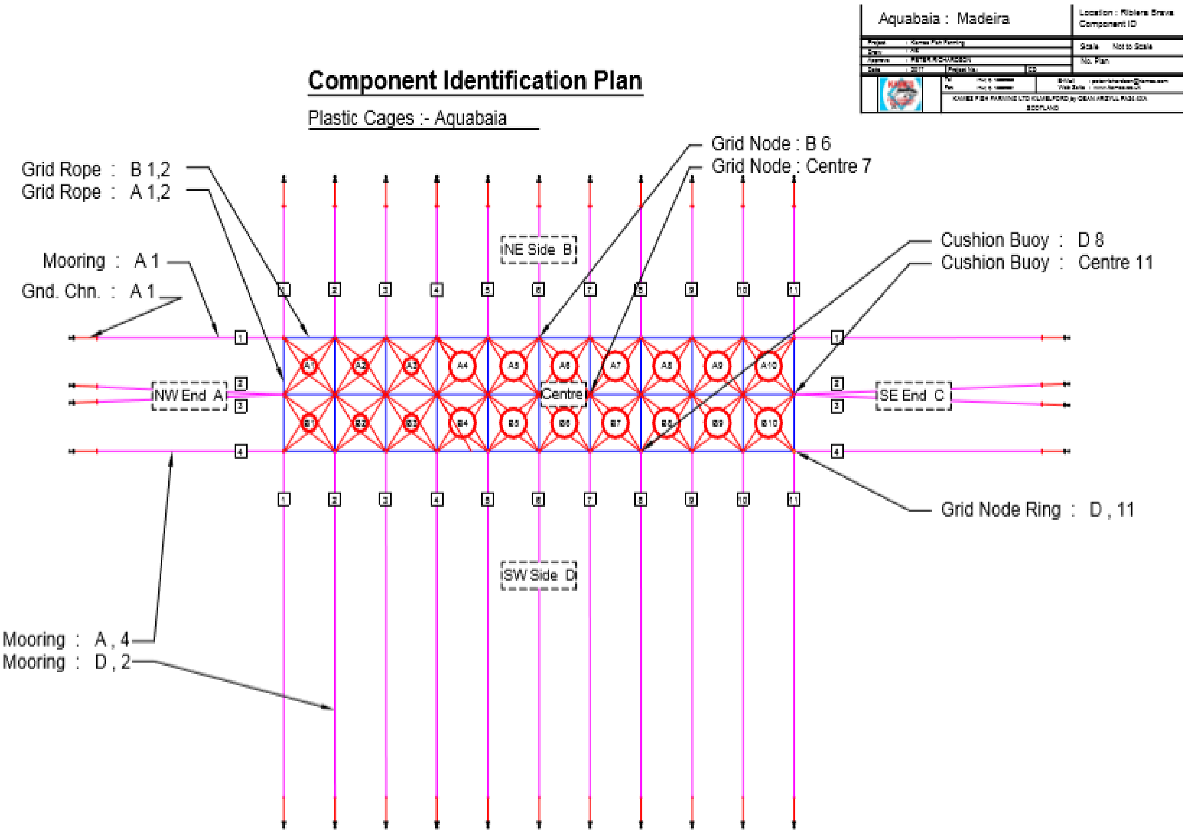
Introduction

Aquaculture is a fast-growing agro-industrial sector (Trujillo et al., 2012) and may help to support the food requirements of the growing world population in the future (Duarte et al., 2009). While aquaculture in Norway is dominated by the Atlantic salmon (Polanco & Bjorndal, 2017), in the Mediterranean, the North Eastern Atlantic Ocean and around Madeira, *S. aurata* represents one of the most important farmed fish species and is commonly reared in open cage aquaculture (Andrade & Gouveia, 2008; Bjørndal & Guillen, 2017; Arechavala-Lopez et al., 2018a). Frequently used is thereby a floating cage-system, in which the net is supported by a floating collar (Beweridge, 2004) (Fig 1.1). Offshore fish farming facilities have the advantage of a wider dispersal of waste products than it would be the case for coastal farms (Holmer, 2010); lower energy cost as the water currents are responsible for the water exchange. Nevertheless, offshore farming facilities are also prone to a high risk of the escapement of fish (Jackson et al., 2015; Thorvaldsen et al., 2015; Arechavala-Lopez et al., 2018a).

Countries such as Norway, Ireland and Scotland have a strict management policy, where fish farm owners are legally required to report escape incidents together with further information, such as the underlaying causes and the extend of the incident. In contrast, in Mediterranean countries no such requirements existed until 2007, which results in a lack of statistics and data regarding escape events (Dempster et al., 2007). Analysis of the statistical data from 2001 to 2006 from the Norwegian Fisheries Directorate revealed, that the most relevant causes for escape events are structural and operational failure (Jackson et al., 2015). Structural failure which can lead to the escape of fish, is often a result of the extreme conditions (Holmer, 2010), that the farming facilities are exposed to in an offshore environment; such as currents or storm events; while structural fatigue and incorrect installation are also relevant (Jensen, 2006).The relevance of structural failure for the escape of individuals from Norwegian fish farms was also pointed out by Jensen et al. (2010).

Even though structural failure only makes a small percentage of escape events, it often results in the release of a high number of fish and is therefore an important factor to consider when investigating fish escapes from farming facilities. In Norwegian fish farms, the relevance of structural failure was already recognized and as a consequence, the Norwegian Standard NS 9415 (NAS, 2003) was introduced as a measure to reduce the amount of escapees (Berstad et al., 2005). In addition to more common weather-related damage on fish farms, escape events can also result from damage inflicted on the net by interactions of fish and other animals. A study by Jackson et. al (2015) showed, that net biting behaviour of farmed fish and predator attacks are the most common causes for escape incidents in the Mediterranean Sea with *S. aurata* and *D. labrax*. During this study, of the fish that were reported to have escaped from fish farms in 242 incidents, seabream made the majority with 76.7%, with two major escape events being especially relevant.

Escapes of fish can also be related to species-specific behaviour of farmed fish, as different species show a variable tendency to interact with, or damage the net cages (Moe et al., 2007; Hansen et al., 2009). Species, as the Atlantic cod *Gadus morhua* (Høy et al., 2012) and the Gilthead seabream (*S. aurata)* were found to have a propensity to bite nets, which can result in holes and as a consequence contribute to the escape of animals (Moe et al., 2007; Papadakis et al., 2012). For *S. aurata* it was shown, that increased rearing density is correlated with an exponential increase in the escape rate and preexistent damage stimulates the fish to bite and further damage the net (Papadakis et al., 2013). Further it was demonstrated, that limited food supply can lead to an alteration in the behaviour of seabream and results in increased interactions with the net (Glaropoulos et al., 2012).



Component Identification :- It is vital that inspection reports accurately identifythe compo0nents inspected, so that they can later be re-located without delay. Otherwise a lot of time, and maybe 1 or 2 dives may be wasted, in relocating a component which is ion need of replacement.

Maintenance Record Forms :- We recommend the systematic scheme shown above, as it permits the use of two Alphanumeric characters, to identify any specific area off the mooring system. The plan above is for the 2 x 10 Plastic Circle System of Ribiera Brava, moored in a Grid Configuration, however Maintenance Managers should adapt there own specific cage numbering.

Figure 2.1 Component identification plan of the farming facility in Ribeira Brava, © Aquabaia

Fish escapes from offshore farming facilities likely led to the introduction of *S. aurata* to Madeira (Alves & Alves, 2002). The underlaying causes so far have not been targeted by scientific work in Madeira. This chapter aims to investigate the occurring escape events in Madeira through the analysis of archive data on net damage provided by the fish farm owners with oceanographic data on sea conditions and further observations made by the farm staff.

Methods

Study area

This study focused on two offshore fish farms on Madeira Island: Calheta and Ribeira Brava. Data collection mainly focused on the fish farming facility Calheta, situated in the South-West of the Island (Fig 2.2)

Figure 2.2 Geographical location of the fish farms in Madeira (Indicated by red stars), that were part of this work,map retrieved and adapted from google.maps © 2019 Inst. Geogr. Nacional, Google

The fish farming facility in Calheta consists of 10 cages (cage number 1-4: 12.7m in diameter and cage number 5-10 with 24m in diameter; Fig 1.1), while the fish farming facility in Ribeira Brava cages consists of a total of 20 net cages (14 cages with 19.5m in diameter and 6 cages with 12.7m in diameter; Fig 2.1).

Data collection

Offshore fish farms from Madeira Island, as in most other locations are visited regularly by staff members, to feed the fish, for maintenance of equipment and other operational duties. At Calheta fish farm, the staff performs dives three times a week, where the net pens are inspected for damage, to be repaired. Recorded damage is noted in an archive, together with other information, such as relevant information on weather conditions, the amount of feed that was provided to the fish and the presence of predators inside the nets.

Compared to the fish farming facility in Calheta, the farms in Ribeira Brava and Caniçal do not have a detailed archive. Here, information is usually only noted, when severe damage occurred in the net pens with the possible escape of fish. The number of escaped fish is usually estimated through the lower amount of feed, that is needed to feed the fish to satiation. However, this approach is connected to a high level of uncertainty and therefore, numbers of escaped fish can only be roughly estimated.

During this study, information on net damage from January 2018 throughout March 2019 was collected from the previously mentioned facilities. Recorded net damage was analysed with respect to local sea conditions. The data used to evaluate the sea condition was provided by the Portuguese Institute for Sea and Atmosphere (IPMA).The measurements included data on significant wave height and maximum wave height for the time period from January 2018 to January 2019 from a buoy deployed near Funchal, about 25km eastern of Calheta and various meteorological measurements provided by IPMA (temperature, windspeed, humidity, water temperature) from station 522 (Observatório Meteorológico do Funchal; 32° 38’ N, 16°53’W, altitude 58m).

Statistical Analysis

Pearson’s coefficient was used to compare correlation of the amount of net damage occurring in the fish farm with wave height (significant wave height and maximum wave height) and significant wave height and maximum wave height with measured values for wind speed (ddf/ffmax). The significance of the obtained values for the correlation coefficient was tested using a one-way ANOVA. Significance levels were set at P<0.05. Calculations were made using the Data Analysis tools of Microsoft Excel 2016.

Results

Sea conditions

As data on sea conditions provided by IPMA revealed, sea conditions show a high degree of variation over the year. During summer (April to October), the recorded average significant wave height was found to be below 1m most of the time, with corresponding maximum wave heights rarely exceeding 2m. Conditions from November to March showed much more extreme conditions. Highest values were recorded at the end of February throughout the middle of march, with the highest value for significant wave height (4.51m) and the highest maximum wave height (10.87m) being recorded on February 28th (Appendix I).

Wind

Data on wind conditions were provided by IPMA. The measurements derive from the station 522 Funchal (Observatório Meteorológico do Funchal; 32° 38’ N, 16°53’W, altitude: 58m). The measurements suggest a variation of wind speed over the year with highest values being reached in winter/spring, similar to the observations made with wave height. The highest value for wind speed measured in Funchal was 81km/h on February 7th, 2018 and the second highest value with 78 km/h on February 28th (Appendix II). Wind speed was correlated versus significant wave height and maximum wave height. Results revealed a significant positive correlation for wind and significant wave height ($R= 0.587$, $P<0.01$) and maximum wave height ($R=0.595$, $P<0.01$) (Appendix II)

Calheta

Table 2.1 Values for the correlation coefficient R and corresponding P-values; resulting from statistcal analysis for significant and maximum wave height versus number of holes detected in the Calheta fish farming facility

Cage number	Cage diameter (m)	Correlation coefficient R (significant wave height, m)	P value	Correlation coefficient R (maximum wave height, m)	P value
1	12.7	0.040	>0.05	0.020	>0.05
2	12.7	0.079	>0.05	0.126	>0.05
3	12.7	0.080	>0.05	0.105	>0.05
4	12.7	0.026	>0.05	0.000	>0.05
5	24	0.084	>0.05	0.110	>0.05
6	24	0.303	<0.01	0.302	<0.01
7	24	0.226	<0.01	0.225	<0.01
8	24	0.200	<0.05	0.196	<0.05
9	24	0.344	<0.01	0.326	<0.01
10	24	0.050	>0.05	0.107	>0.05

Results from the inspection dives at the farming facility (number of holes in the net) were plotted versus the significant wave height and the maximum wave height. Results indicated a positive correlation, except for cage 4, which showed no correlation between maximum wave height and the number of holes detected in the net pens. For the 12.7m diameter cages (Cage 1-4) calculations point towards a non-significant positive correlation ($P>0.05$) between wave height and the number of holes in the net with the highest value for R being 0.126. Compared to that, the 24m diameter cages (Cage 5-10) showed values of R up to 0.344, indicating a stronger positive correlation between wave height and the occurring damage. Cages 6, 7, 8 and 9 revealed a significant ($P<0.05$) positive correlation between significant wave height and maximum wave height and the amount of recorded damage at the farm (Tab 2.1).

As the analysis revealed, cage 1-4 show a high amount of net damage in summer (cage 1: 10 holes on 10th of August; cage 2: 6 holes on 10th, 20th and 27th of august; cage 3: 7 holes on 13th and 31st of august; cage 4: 25 holes on 18th of July; Appendix III). Data on waves, as well as wind measurements suggest no extreme conditions in that period. Therefore, it is likely, that this net damage did not result from structural failure.

The larger cages showed the highest numbers of net damage in winter or early spring (cage 5: 65 holes on December 21st and 32 holes on December 25th; cage 6: 12 holes on March 2nd; cage 7: 12 holes on November 23rd, December 21st and December 27th ; cage 8: 11 holes on January 15th and March 11th 2019; cage 9: 14 holes on March 2nd and cage 10: 10 holes on December 21st; Appendix III)

Ribeira Brava

In February 2018, Madeira experienced extreme weather conditions, which resulted in the formation of waves with a maximum height of 10.87m according to measurements by IPMA. These extreme conditions caused severe damage at the farming facility, including deformation and breakage of the floating collar and partwise or total sinking of entire net pens (Fig 2.3, Fig 2.4). Due to this structural failure, the destruction of several net pens resulted in the release of >1.000.000 individuals of *S. aurata*.

Figure 2.3 The offshore fish arming facility in Ribeira Brava after extreme weather conditions in February 2018 with 6 net pens suffering extreme damage due to structural failure, © Aquabaia

Figure 2.4 Damage at the fish farm in Ribeira Bava resulting from extreme weather conditions in February 2018: Deformation of the floating tubes (c, e, f, h), including strangulation and breakage of the floating tubes (g, I, j, k), dislocation of the surrounding walkways (e), sinking of the net pen; with only the bird-protection net remaining at the surface, (d) and partial sinking of the net pen (a, b, e),© Aquabaia

Discussion

Historically, cage culture occurred mainly in sheltered environments. As such suitable locations are finite, trends in the industry point towards larger facilities, that are operating in more exposed offshore environments (Huguenin, 1997, Pérez et al, 2003). As consequence, offshore farming facilities are facing more extreme conditions (Holmer, 2010). Results suggest a significant positive correlation ($p<0.05$) between significant wave height and maximum wave height and the amount of net damage for the larger 24m diameter cages number 6, 7, 8 and 9 of the fish farming facility in Calheta; pointing towards the relevance of sea conditions in respect of occurring damage in offshore farming facilities. These findings support the results of previous studies, such as Jensen (2006), Jensen et al. (2010) and Jackson et al. (2015).The correlation between maximum wave height and significant wave height produced relatively similar values for R, which suggests, that both measurements appear to be equally representative for the sea conditions.

The smaller cages of the farming facility showed a non-significant positive correlation with increasing wave height from $R= 0$, $P>0.05$ to $R=0.126$, $P>0.05$ These small values for R may derive from the fact, that none of the small 12.7m cages were in use during the period with highest measured values for waves in February and March 2018, which could have influenced the results by putting more emphasis on non-weather related factors. Further, there was no wave data available for dates past 30th of January 2019; not allowing to include the whole dataset of recorded net damage into our analysis. The reduction of 12.7m diameter cages is a measure to reduce the amount of weather-related damage by operating with the lowest number of cages possible in the time with a high risk of storms and extreme sea conditions. Cages are also frequently removed from the water and washed, without repairing pre-existent damage, which then results in the presence of holes in the net from the start (Personal comment, Mr. Ferreira França, production foreman of Marismar). High numbers of holes in the nets occurring in times with low values for wave height could also result from predators biting the nets. Particularly individuals of *Pomatomus saltatrix* were commonly sighted around the facility and recorded inside the nets, feeding on farmed fish. These incidents are more common during summer months (Personal comment, Mr. Ferreira França, production foreman of Marismar)

The influence of sea conditions on a farming facility is depending on the physical properties of the farm (Lee et al., 2008). Therefore, it is also likely, that the larger cages (24m) show a higher vulnerability regarding rough sea conditions, as shown by higher values for R from R=0.05, P>0.05 to R=0.344, P<0.01. This might be the reason for high numbers of net damage in the 24m cages during winter, when predators, such as *Pomatomus saltatrix* are less abundant. The obtained values for the correlation factor R may even underestimate the relevance of sea conditions, since diving operations at the farm do not take place in unsuitable, rough sea conditions. Consequently, net damage is usually only noted after stormy periods, which may lead to inaccuracies and lower values for the correlation factor R.

However, there are cases, when structural failure is unlikely to have caused a large amount of damage on the 24m cages of the farming facility in Calheta during winter months. For instance, cage 5 shows the highest number of damage of all cages (65 holes), that were recorded on December 21st and also Cage 10 shows the highest number of holes on December 21st, when the wave data did not indicate rough sea conditions the day before and on said day (significant wave height on December 20th and 21st 0.72m and 0.68m respectively, with maximum wave heights of 1.66m and 1.77m). In the case of cage 5, there were no inspection dives performed between December 10th and December 21st, as the cycle of cage 5 was finished on December 12th and the cage was not in use until December 19th. The damage at this cage could therefore also be the result of operational failure during the replacement of the net cage. However, this does not provide an explanation for the high degree of damage recorded during this time at cage 10. It should be taken into account, that multiple factors may contribute to the formation of holes at the nets of the fish farm in Calheta. For example, regarding background data, it was not examined, how many cycles the used nets have already spent in the water and holes may also result from wear and tear of the nets (Thorvaldsen et al., 2015).

In direct comparison, the farming facilities in Ribeira Brava suffered more severe damage in February 2018, than the facility in Calheta. Calculations with wind speed and maximum wave height (R= 0.595, P<0.05) suggest that high wind velocities will most likely result in the formation of higher waves. As measurements on wind and wave data derived from a location roughly 15km from Ribeira Brava and approximately 25km from Calheta, it is also possible that the farming locations experienced different conditions compared to the measurements by IPMA. It may therefore be possible, that conditions led to the formation of higher waves in Ribeira Brava, likely leading to increased mechanical stress on the Ribeira Brava fish farming facility. Further, in the fish farm of Ribeira Brava a different net size (19.5m diameter compared to 24m diameter in Calheta) is used. It was shown that the reaction of fish farms towards currents is depending on the size of the net cage and weight system (Moe et al., 2010). The influence of currents was not investigated in this thesis. But generally, the size of the net of a fish farm (section area) may have an influence on the resistance during storms and extreme weather conditions and explain the differences between the farms at the two locations.

The collapse of several cages at the farming facility in Ribeira Brave led to the release of >1,000,000 individuals of *Sparus aurata*. In a comparable incident between December 2009 and January 2010 near the Island la Palma extreme weather conditions lead to the release of approximately 1.5 million individuals of *D. labrax* (90%) and *S. aurata* (10%). This incident lead to a significant increase in the mean trophic level (Toledo-Guedes et al., 2014) and was considered one of the biggest escape events ever documented. The number of fish released from the offshore fish farm in Ribera Brava in February 2018 led to the release of a similar number of fish, thus putting further emphasis on the relevance of *S. aurata* escapes from Madeiran fish farming facilities and the involvement of extreme sea conditions in these incidents.

Conclusion

Several studies already pointed out that structural failure appears to be an important factor regarding escape events from offshore fish farms (Jensen, 2006; Jensen et al., 2010 & Jackson, et al., 2015). This is supported by a high number of damage at the farming facility in Calheta, that were reported during periods with stormy sea conditions and a significant positive correlation between significant and maximum wave height and the amount of net damage. Especially the collapse of several cages of the farming facility in Ribeira Brava with a resulting release of >1,000,000 Gilthead seabream likely resulted from structural failure during a period with extreme weather conditions, with waves in excess of 10m. This emphasizes the relevance of extreme sea conditions on escape events with offshore fish farms.

The present data does not allow to fully distinguish between weather related net damage and damage resulting from predator attack, the net biting behaviour of the reared fish or other causes, such as boat strikes, operational failures during the harvest of the farmed fish, incorrect installation or other environmental factors, such as strong currents. As some of the cages showed high numbers of net damage in periods with calm sea conditions, it is unlikely, that structural failure was the origin of these. According to statements of Mr. Ferreira França of the offshore fish farm in Calheta it is more likely, that this damage was caused by predator attack due to a high number of *P. saltatrix* spotted over summer months.

To identify the source of damage in the net it would be necessary to use a different scientific approach that allows to monitor the facility over a longer period. A fixed underwater video camera system could be used to monitor the cage and the animals around it. Additionally, the use of a fixed camera system would further allow to observe the reaction of the fish farm to rough sea conditions and to detect the formation of holes in real time, when no filming or diving operations are possible. This would allow to calculate the correlation of occurring damage in respect to weather data in real time, which would most likely improve the accuracy of the calculations made. The investigations during this study revealed a known limitation (Dempster et al., 2007): Information on escape events and the management policy in Southern European countries, like Madeira, Portugal is often incomplete.

Chapter 3 Analysis of the wild fish community around fish farms in Madeira

Introduction

Fish aggregating devices (FADs) are floating constructions, used in commercial fisheries to attract pelagic fish, thus facilitating the catch of species, such as tunas (Moreno et al., 2016). Cage fish farms in coastal areas resemble large fish aggregating devices (Dempster et al., 2002). Generally, floating objects act as protection from predatory species and provide a higher availability of food (Castro et al., 2002). Fish farms have the capacity to attract wild fish and farming activity can lead to high densities of wild fish around fish farming facilities (Dempster et al., 2002, 2004). Compared to traditional FADs, the attraction of wild fish to fish farms may be enhanced by the feed that is being released into the environment (Bjordal & Skar, 1992).In the Mediterranean, wild fish communities associated with farming facilities were shown to vary in terms of abundance and community structure (Dempster et al., 2002, 2004, 2005; Valle et al., 2007). Studies by Andrade and Gouveia (2001) in Madeira Island and by Tuya et al. (2006) in Gran Canaria compared the abundance and structure of wild demersal fish beneath fish farms in at Gran Canaria, revealing a strong decline in the aggregative effect of the farming facility, after the farming activity stopped, which was mainly related to the removal of daily feeding.

A high abundance of wild fish and other animals around farming facilities may also be relevant in terms of escape events, as species associated with fish farms are capable of causing an escape event through breakage of the net, the enhancement of already existing damage and/or distress of the farmed fish inside the net (Arechavala-Lopez et al., 2018a) Throughout the Mediterranean Sea, the bluefish (*Pomatomus saltatrix*) is commonly reported near fish farms (Dempster et al., 2002; Valle et al., 2007). The species may be a potentially problematic predator, as it was reported entering farming facilities and preying on farmed fish, which most likely leads to a decrease in the productivity of farmed *S. aurata* (Sanchez-Jerez et al., 2008). In Madeira, *P. saltatrix* is a common coastal species and was observed within the farming facilities, likely causing damage and possibly the escape of farmed fish. Also, not only fish may be responsible for damage occurring in farming facilities, as in Turkey and Chile, monk seals have caused damage to the net pens, which resulted in escape events (Güçlüsoy & Savas., 2003).

The evaluation of the species can be achieved by visual census of the present fish during diving operations; representing a method with low impact on the ecosystem (Holubová et al., 2019). However, factors, such as depth and diving time limit the applicability of this method (Pinheiro et al., 2015). A common approach is the installation of remote underwater camera systems (RUV), which were shown to detect a higher number of fish species and individuals, than visual census (Zarco-Perello & Enríquez, 2019). In our study, a simple mobile video camera system was used to document the wild fish communities present around fish farming cages at the Marismar facilities in Calheta, Madeira. The aims of this chapter were to examine the wild fish community around Madeira's offshore fish farms, to provide evidence for the presence of top carnivorous species and their potential role in the escape events regarding *S. aurata* and to test the applicability of a video camera supporting system for the evaluation of the fish species community around fish farming cages.

Methods

A camera supporting system was assembled, consisting of a 5m long pole aluminium pole with a waterproof camera (Go pro Hero7) at the end (Fig 3.1). Video footage was made once or twice weekly (depending on the fish farms activities and sea conditions), from December 14th to April 26th, when accompanying farm workers during their regular visits to the cages in between 14:00-16:30h.

Figure 3.1 Assessment of the wild fish community structure near the fish farm in Calheta, Madeira, Portugal with a telescopic pole and an underwater camera

The pole was submerged at one point to a depth of approximately 50cm with the camera filming downwards in a 45° angle. Then a video sequence filming the fish community was created while walking around the farming facility, timed to five minutes to complete the full circle. Handrails of fish cage were marked at the 4 cardinal points, allowing to check the position of fish. At these points, the camera system was submerged until the maximum possible depth. The fish species visible in the videos were later identified with the help of the checklist for Madeira's fish species by www.fishbase.eu (Froese & Pauly, 2019).

The data gathered from the video material was treated as presence/absence data and the schools noted; allowing to gain a qualitative overview of the species present around the farming cages. The species richness S was calculated for each day the fish farming facility was visited.

$$\text{Species Richness } (S) = \text{Number of species present in one day}$$

Results

Within this study the fish community around the farming facility in Calheta was assessed from December 14th until April 26th. During this work we filmed on 19 days, resulting in 167GB of video material to be analysed. A total of 6 species of osteichthyes were identified from the video material; the species belong to the families *Sphyraenidae, Carangidae, Balistidae, Sparidae* and *Clupeidae*. The values for species richness S thereby ranged from 2, to 4; the highest value for S was obtained on December 14th, 2018, January 11th 2019 and January 15th 2019.The video footage shows that the two most common species around the farming facilities are *Trachinotus ovatus* and *Sardinella maderensis*, as these two species could be observed in every occasion the farming facility was visited. Especially *T. ovatus* was frequently present in large schools (Tab 3.1, Fig 3.2), while the number of *S. maderensis* appeared to be comparatively smaller and the species was mostly sighted in small groups (Fig 3.3)

Figure 3.2 School of *Trachinotus ovatus* aggregating around the offshore farming facility in Calheta, Madeira.

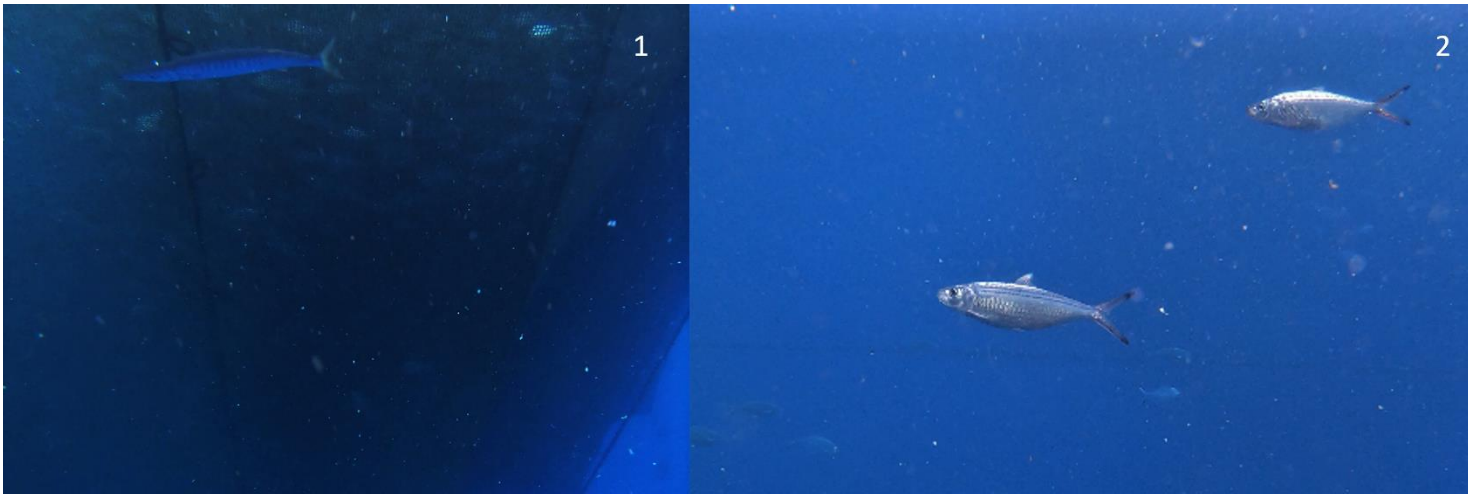


Figure 3.3 *Sphyraena viridensis* (1) and *Sardinella maderensis* (2) near the offshore farming facility in Calheta, Madeira

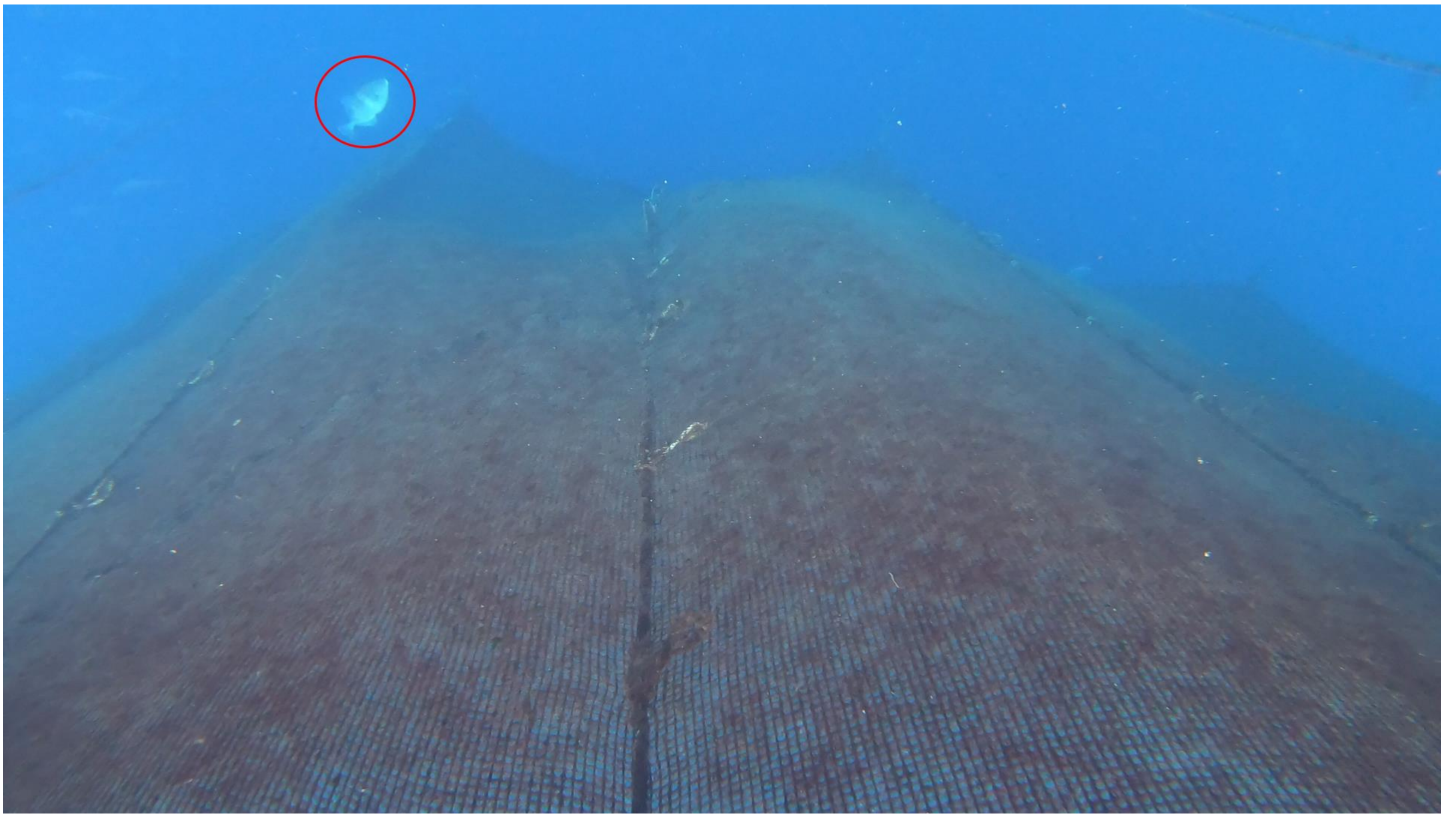


Figure 3.4 Individual of *Balistes capriscus* (indicated by red circle) near the offshore farming facility of Calheta, Madeira.

Figure 3.5 Turtle (indicated by red circle) filmed and photographed near the offshore farming facility of Calheta, Madeira

Table 3.1 List of fish species sighted and identified near the fish farming facility in Calheta with a remark on the food habits of the species and their abundance in the video material

Species	**Family**	**Food Habits**	**Abundance** (Present in % of the videos)
Trachinotus ovatus	*Carangidae*	Planktivorous/Carnivorous	100%
Sardninella maderensis	*Clupeidae*	Planktivorous	100%
Sphyraena viridensis	*Sphyraenidae*	Top carnivorous	21%
Balistes capriscus	*Balistidae*	Carnivorous	21%
Oblada melanura	*Sparidae*	Omnivorous	11%
Trachurus picturatus	*Carangidae*	Carnivorous	5%

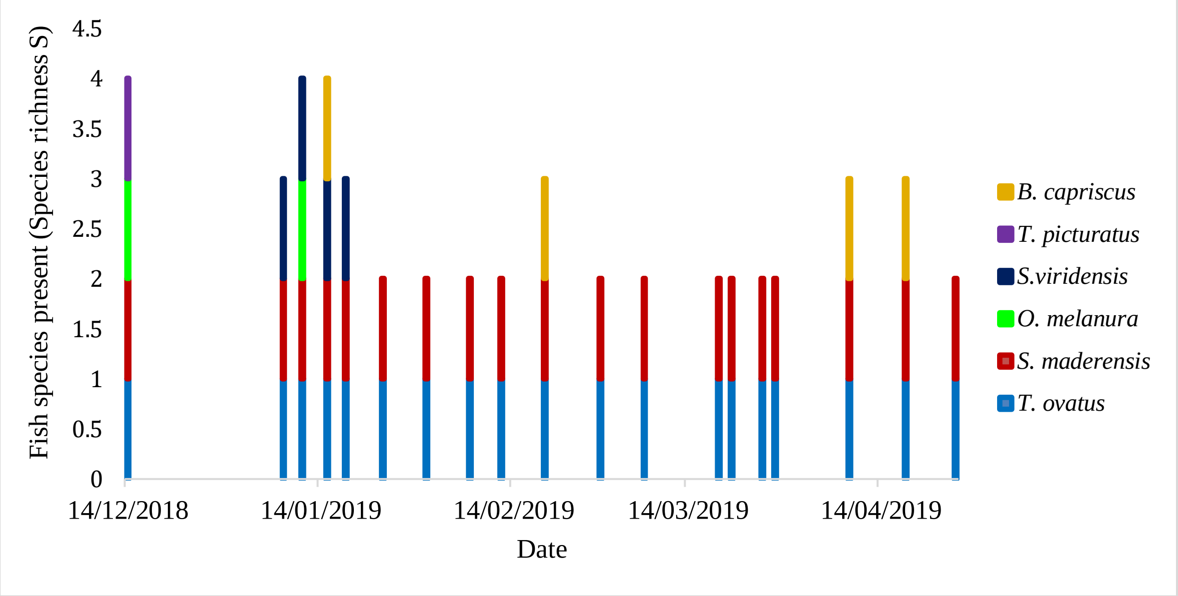


Figure 3.6 Bar chart indicating the species sighted and identified (Species richness S) near the offshore fish farming facility in Calheta, Madeira and the corresponding time of the sightings

Other species recorded near the farming facility were *Oblada melanura*, *Sphyraena viridensis*, *Trachurus picturatus* and *Balistes capriscus.* Other than the mentioned species could not be identified with certainty. According to observations of the staff of the facility, during our study, large individuals of *P.saltatrix* were caught inside the farming facility. Together with the previously mentioned fish species, on March 7th a turtle was sighted and photographed near the farming facility (Fig 3.5).

Discussion

Offshore fish farms are known to attract a great number of wild fish, that are often present in high densities (Dempster et al., 2002; Dempster et al., 2004; Dempster et al., 2005; Tuya et al., 2006). Species, such as *T. ovatus* and *S. maderensis* were already found to be associated with Mediterranean fish farms (Dempster et al., 2002 & Ballester-Moltó et al., 2017) and are likely to feed on excess food and faeces from the farming facility. Other species that were sighted may be relevant in terms of damage to the net cages. Triggerfish, such as *B. capriscus* possess strong jaws and teeth that are able to process a variety of food items including hard-shelled prey (McCord & Westneat, 2016). Studies on this species regarding interactions with fish farms remain scarce. However, it seems likely that the species is capable of damaging nets of fish farming facilities. *B. capriscus* was commonly reported by the farm divers underneath the net pens feeding on dead fish, likely resulting in the formation of holes in the net. The presence of *P. saltatrix* could not be confirmed with the present video material. Occasionally, large fish could be seen on the videos. However, the limited length of the camera pole and the resulting angle of the camera system combined with the low water visibility near the farm did not allow for the identification of the species. The shape of the fish resembled that of *P. saltatrix.*

As the assessment of the fish species was always done while the farm staff fed the farmed fish, it possible, that top carnivorous predators were not present at that time. Potentially, loud noise from the boat and the engine powered feeding machine may have led to absence or vertical movements of some species into deeper zones. In the Mediterranean Sea it was shown by Sarà et al. (2007) with *Thynnus thynnus* that boat noise can provoke behavioural alterations and vertical migrations. The farm staff commonly performs their dive operations equipped with spear fishing gear to be able to eliminate large predators around or within the fish farm. Studies by Lindfield et al. (2014), Gray et al. (2016) and Sbragaglia et al. (2018) have pointed out the influences of fishing pressure on fish behaviour, especially related to non-closed-circuit diving gear. Possibly, the absence of top carnivorous species near the offshore fish farm results from the species avoidance of the location when operations are made to avoid fishing pressure by the farm staff. In opposition, the feed wastes might have attracted schools of gregarious fish such as *S. maderensis* and *T. ovatus*.

The abundance of top carnivorous fish near Madeira Island is reduced compared to the nearby Selvagens Islands due to overfishing of commercial relevant high-trophic level fish (Hermida & Delgado, 2016; Friedlander et al., 2017), which may be an additional factor leading to the lack of top predators sighted during this study. According to personal statements, the relevant predators, which might be responsible for occurring damage at the farming facility are more present during summer. This could also provide an explanation for the high number of damage, that was recorded in summer months at some of the cages at the farm in Calheta and explain the absence of larger predators in the video material during our study period over winter and spring months. The assemblage of species present at Calheta fish farm was in agreement with a previous study by Andrade and Gouveia (2001) at Baia de Abra farm, when in full operation and the cages stocked with farmed fish.

Conclusion

Fish farms in Madeira act as large fish aggregating devices, that were shown to attract wild fish, mainly *T. ovatus* and *S. maderensis*, according to data collected during video surveys in this study. Associated wild fish may be relevant in terms of the reduction of wastes resulting from uneaten food pellets (Rieraa, et al., 2017). Data analysis during this study revealed the presence of species, that might be capable of causing damage at the nets, such as *B. capriscus* and *S.viridensis*. However, the presence of large predators such as *P. saltatrix*, suspected to cause net damage, although reported by farm staff, could not be verified.

The methodology used in this study was connected to various limitations, as the used camera pole only allowed to film fish within the first meters of the water column, not allowing to film underneath the net cages. Further, due to the limited time frame in which this study was performed, it was impossible to gain an overview over the fish population over the year and the time the fish community was assessed was dependant on the feeding schedule of the farm. Hence, the wild fish community around the farming facility may be different during summer months or at another time of day, when no farm operations are made.

However, the method tested could be considered a suitable tool to assess the fish species community associated with the fish farming facilities of Madeira. The resolution of the recorded video material allowed for the identification of 6 fish species, with one of the biggest advantages being the low operational costs of the used device and the simplicity of the operation; species census could be performed by accompanying the fish farm staff without the necessity of diving operations or the use of a separate boat. The timeframe of this this study did not allow for enhanced analysis of the species associated with the fish farm. Although the high resolution of the produced video material would likely allow for a quantitative analysis of the species community. Future research would likely benefit from the additional use of a fixed camera system to overcome previously mentioned limitations.

Chapter 4 Analysis of the population of previously escaped seabream *S. aurata* around Madeira Island

Introduction

Most farming activities of *S. aurata* take place within the native distribution range of the species. Madeira Island was initially not inhabited by *S. aurata* and the presence of the gilthead seabream was first confirmed, after commercial farming of the species started in offshore fish farms (Alves & Alves, 2002). Aquaculture of fish in areas, where the species were formerly absent is already commonly practiced (Casal, 2006; Arismendi et al., 2009; Liao et al., 2010). Damage in the farming facilities provoked by technical failure due to extreme weather conditions and other factors can lead to the repetitive release of locally absent fish in areas, where open cage aquaculture is taking place (Jensen, et al., 2010).

S. aurata is a protandrous hermaphrodite, that matures as a male within the first or second year and then changes into a female during the second or third year (Bauchot & Hureau, 1990; Buxton & Garratt, 1990). Estimations for the total length at first sexual maturity suggest 20.5 and 22.8 cm, which is equivalent to 0.47 years and 0.83 years for males and females, respectively (Ahmed, 2011). The suggested lengths at maturity mentioned by www.fishbase.eu (Froese & Pauly, 2019) are 20-30cm (males) and 33-40cm (females) for the Mediterranean Sea and the Eastern Atlantic. The spawning period is during winter from October to December or January (Bauchot & Hureau, 1986; Chaoui et al., 2006).

S. aurata possess specialized teeth (Fig 4.1). The species feeds a variety of prey, that (depending on the size of the fish) includes mainly invertebrates, such as bivalves, gastropods, amphipods, polychaets and nematodes (Tancioni et al., 2003) In Southern Portugal, *Sparus aurata* was found to prey on bivalves and gastropods and appears to be have a more specialized diet than other seabream species, such as *Spondyliosoma cantharus* and *Diplodus sargus* (Pita et al., 2002). However, apparently the preferred food source of previously escaped individuals of *S. aurata* in Madeira has not been the target of previous scientific studies.

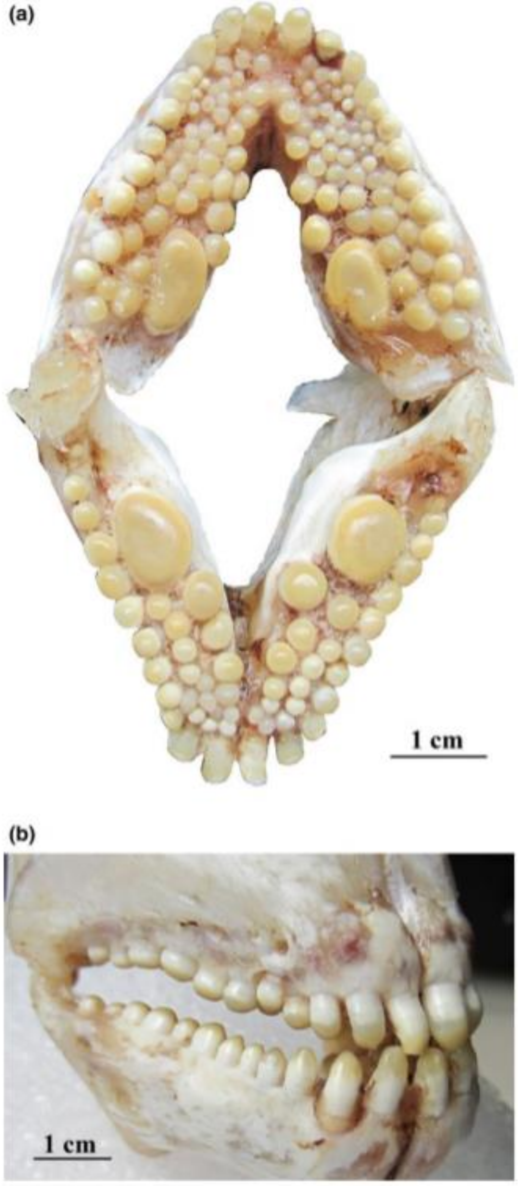


Figure 4.1 Skull and teeth structure of a 14 year old individual of *S. aurata* ,(a) molar teeth, (b) canines; retrieved and adapted from Aydin (2018).

Sparus aurata has a high dispersion in the first days after escaping from a fish farm and is able to adapt and prey on natural food sources one week after the escape (Arechavala-Lopez et al., 2012). So far, the ecological consequences of the presence of *S. aurata* around Madeira and generally outside the natural distribution range of the species remain largely unstudied and data on the population-size and -structure of *S. aurata* in Madeiran waters is lacking. This study further sets the objective to gather data on the population of previously escaped gilthead seabream, to help evaluate possible ecological impacts and to assess, whether there is a risk of a self-sustaining population, which may allow the justification for further research or specific management plans.

Methods

Sampling and laboratory techniques

A total of 38 individuals of S. aurata was sampled on February 26th (10 fish), February 27th(5 fish), February 28th (6 fish), March 26th (1 fish), March 27th (1 fish), April 25th (8 fish) and April 29th (7 fish). Fish were caught in the harbour of Calheta with recreational fishing gear (hook and line). Hereby, squid was used as bait. Immediately after being caught, the fish were sedated by a hit on the head and killed by thermoshock by placing the fish in an ice-filled box. The fish remained on ice until the removal of the stomach, which was always performed soon after on the same day at the Mariculture Centre Institute of Calheta.

In the laboratory, fish were measured, weighted and disected. Thereby the fork length, standard length and total length was noted. The obtained lengths were used to sort the fish into size classes of 0.5cm. The stomachs of the fish were removed, weighted and fixed in 70% vol. ethanol solution. Stomachs and contained prey and particles then were inspected visually with the help of a stereoscope. Identification of prey types was done to the lowest taxonomic level possible. Complementary to the stomach content analysis, gonads of the fish were analysed macroscopically with the help of Ungaro (2008) and categorized in stages of maturity according to Holden & Raitt (1974).

Calculations

Calculations were made using the following equations.

Percentage of each prey type:

$$\frac{\text{Weight of one specific prey type (g)}}{\text{Weight of all prey detected in the stomachs (g)}} \times 100$$

Percentage of fish containing one specific prey type:

$$\frac{\text{Number of fish containing one specific prey type}}{\text{Total number of fish}} \times 100$$

Fullness Index:

$$\frac{\text{Number of empty stomachs}}{\text{Number of all stomachs}} \times 100$$

Results

Size classes and weight

Measurements showed fork lengths ranging from 15.5cm to 27cm (total length 16.5cm to 29cm). which corresponds to a weight ranging from 60.89g to 457.2g (mean weight 192.92 g ± 78.28). Fork length and body weight of the fish were correlated against each other (R=0.886, P>0.01). A scatter plot of length and weight is presented in Fig 4.3. Most fish were between 20cm and 25cm in fork length (mean FL: 21.75cm ±2.59)

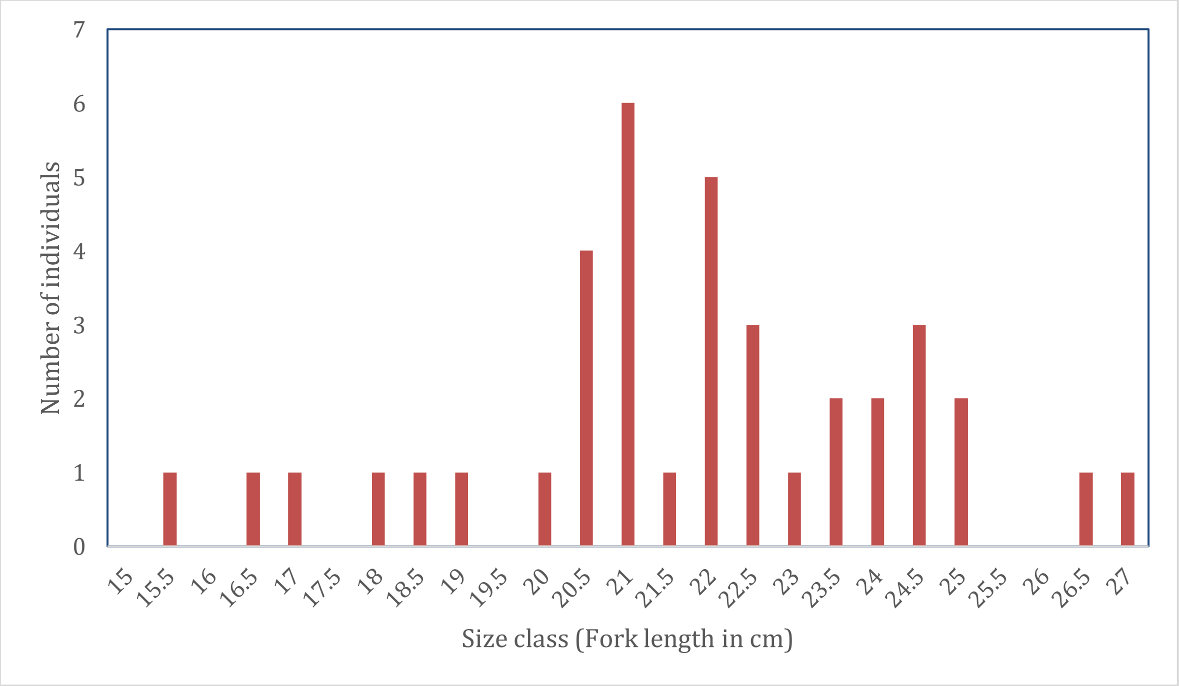


Figure 4.2 Bar chart showing the length frequency distribution of the specimens of *S. aurata* caught during this study

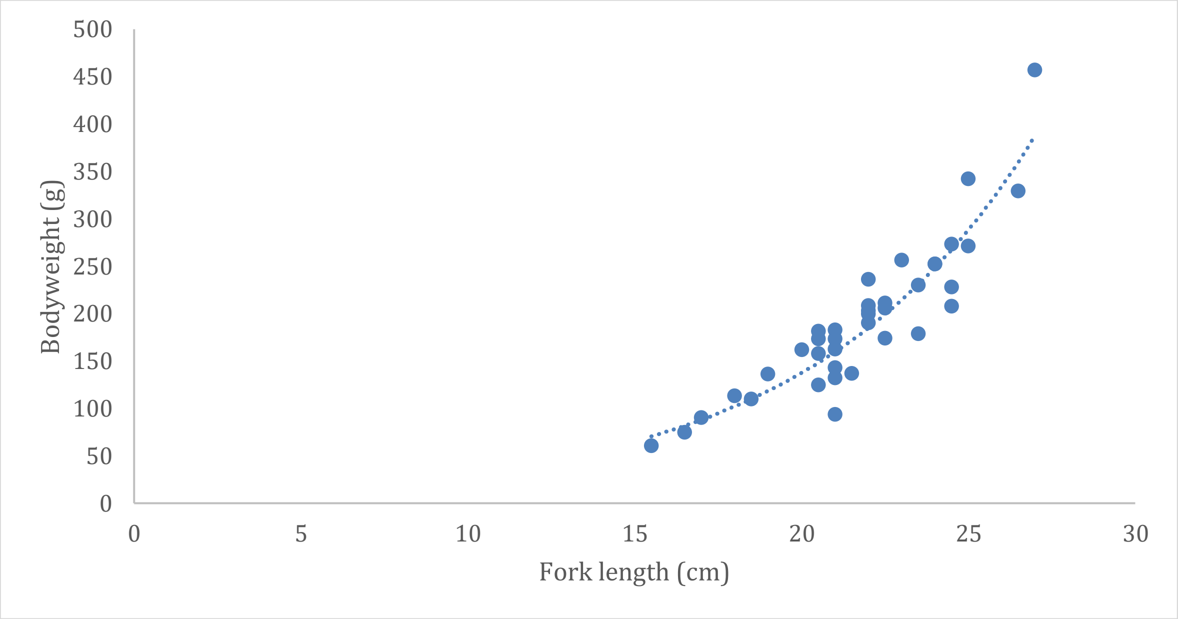


Figure 4.3 Scatterplot of the length-weight relationship between fork-length (cm) and bodyweight (g)of the sampled specimens of *S. aurata*, R=0.886, P<0.01

State of maturity

Visual inspection of the sampled specimens did not reveal signs of sexual maturity, as gonads were barely visible and almost translucent, indicating that the sampled fish were immature/ undetermined state.

Stomach content analysis

Consumed prey was analysed visually to the lowest level possible. A total of 28 prey items could be found within the 38 fish and16 fish revealed an empty stomach. The most common prey type was referred to the category “fish” (scales, bones and tissue that could undoubtedly be identified as fish), which was the most common prey type and could be found in 31.6% of the fish (12 individuals). Fish represented 50.3% of the total weight of consumed prey.

After bait (10.5% of the fish contained bait in their stomachs and bait made 26.6% of the total weight of the consumed prey), food pellets most likely derived from aquaculture made the third most important food item (7.9% of the fish contained pellets in their stomach; 15.1% of the total weight of consumed prey) (Fig 4.4, Fig 4.5, Tab 4.1).

The fullness index of the sampled fish was calculated to be 42.1%.

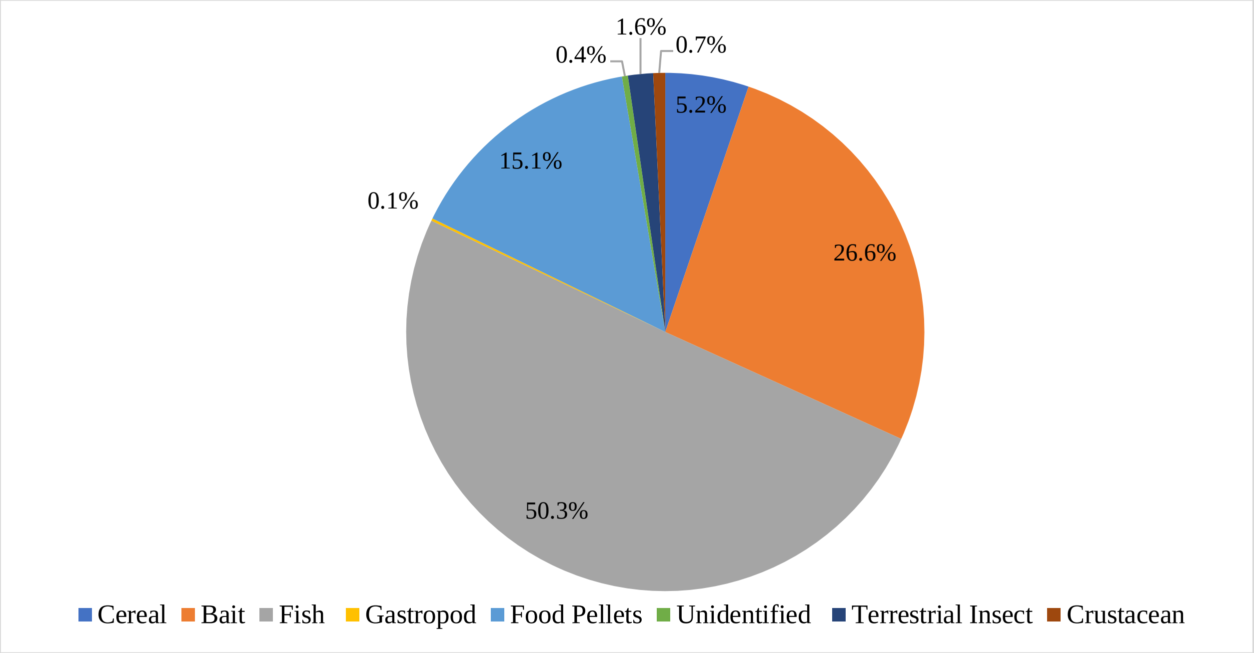


Figure 4.4 Pie chart of detected prey types in *S. aurata* and percentage of the weight of each prey type compared to the weight of total prey (%)

Table 4.1 Prey types found within sampled individuals of S. aurata during this study and the corresponding weight of the specific prey type (g), including the percentage of total prey (%).

Prey type	**Total weight per prey type (g)**	**Percentage of total prey (%)**	**Percentage of fish containing specific prey type (%)**
Cereal	0.7	5.2	2.6
Bait	3.57	26.6	10.5
Fish	6.76	50.3	31.6
Gastropod	0.02	0.1	2.6
Food Pellets	2.03	15.1	7.9
Unidentified	0.05	0.4	2.6
Terrestrial Insect	0.21	1.6	2.6
Crustacean	0.1	0.7	2.6

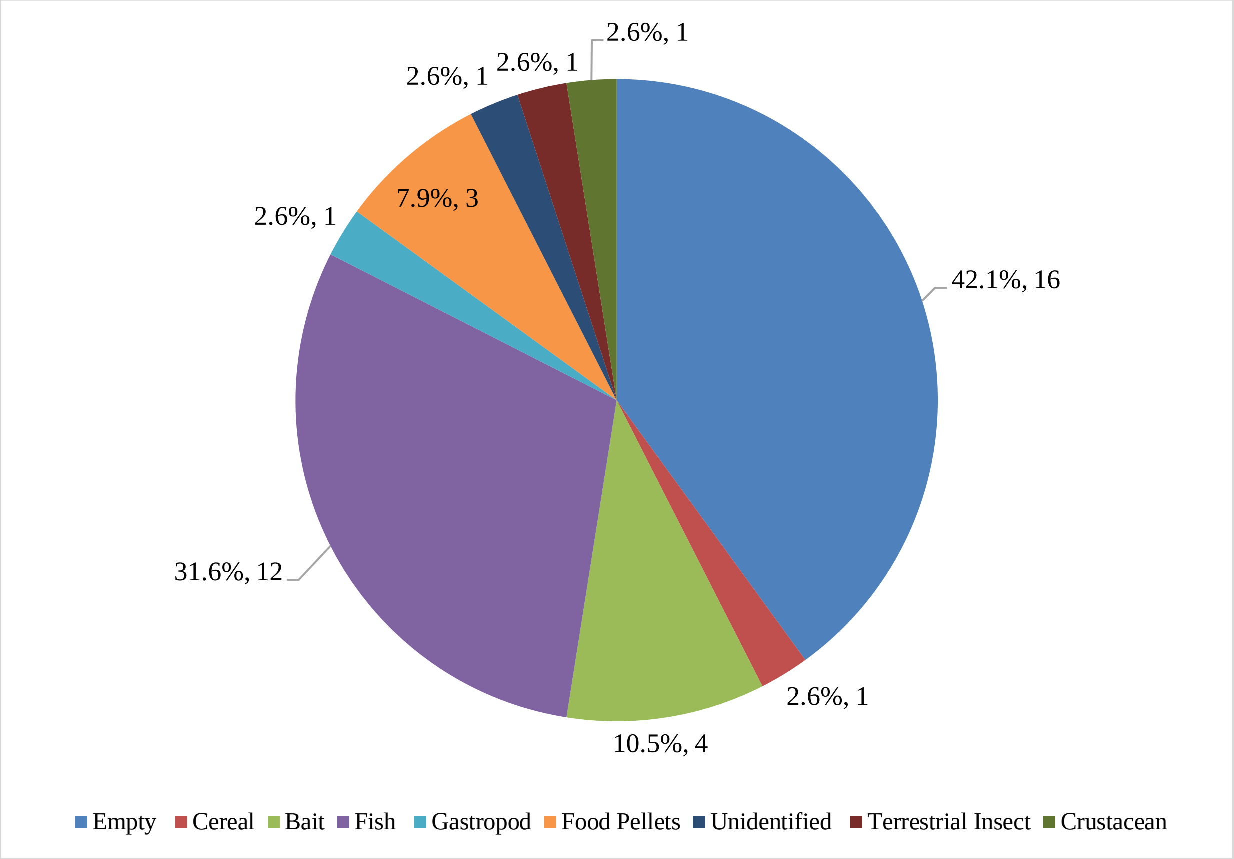


Figure 4.5 Pie chart of detected prey types, percentage (%) of individuals of *S. aurata* containing one specific pre type and the corresponding number of individuals (n=38)

Discussion

This work represents the first approach of a study targeting previously escaped *S. aurata* in the wild in Madeira Island. During this study, 38 individuals of *S. aurata* were caught in the harbor of Calheta, where the animals could be observed from the piers. The animals were measured to be below 30cm in total length and a visual inspection of the gonads showed, that the sampled animals were immature individuals. Therefore, it could not be proven, that there is an acute risk of a self-sustaining population and that escapees thrive and reproduce in the wild.

Within the natural distribution range of the species, the natural diet consists mainly of bivalves, gastropods and other invertrebrates (Pita et al., 2002; Tancionia et al., 2003). According to the results of the stomach content analysis, the preferred prey of the sampled fish is fish, which made 50.3% of the total stomach contents. According to Arechavala-Lopez et al. (2012), *S. aurata* possess the ability to adapt to new food sources within one week after the escape from a farming facility.

It is likely, that the sampled fish find prey fish in large quantities in the harbor. The digested fish may originate from discards of local fisheries, but is also possible, that *S. aurata* prey on small fish, which would imply a possible risk of predation and food competition for local species. As no further examinations of the consumed fish were made, it is not possible to identify the exact species that were consumed. With 15.1% pellets represent the second largest fraction of stomach contents apart from the bait that was used to catch the fish. The harbor of Calheta is used to load commercial feed on the fish farm boats. In the process, pellets fall into the water and then represent a known food source for *S. aurata*. In fact, most of the *S. aurata* seen in the harbor were accumulating next to the crane, where the food is loaded on the boat of the fish farms, seemingly being used to feeding on the excess food falling into the water. However, even with bait included, 42.1% of the fish were found to have an empty stomach. This relatively large percentage might indicate a lack of suitable food sources for the previously escaped fish, or their lack of abilities to successfully find and capture food in the wild.

Conclusion

The results of this study allowed to gain a first insight into the diet of previously escaped *S. aurata* from Madeiran fish farms; indicating a different diet than in the natural distribution range of the species. Fish were the primary food source followed by food pellets derived from aquaculture Results of this study did not provide evidence for the presence of mature individuals in the escaped population and the implied risk of a self sulf-sustaining population of *S. aurata* around Madeira. However, the limited number of sampled fish (38) does not represent a large dataset and consequently the results of this study can only be regarded as preliminary. Future research, including a larger number of sampled specimens, different sampling locations and a more detailed analysis (ideally implying a genetic approach for the identification of consumed prey) is needed to fully assess the role of *S. aurata* in the environment of Madeira.

Final considerations

Sparus aurata represents a common species in European fish farms (FAO, 2016; Arechavala-Lopez et al., 2018a). Previous studies, such as Jensen (2006) Jensen et al. (2010) and Arechavala-Lopez et al. (2018a) have already pointed out the relevance of extreme weather conditions and the resulting escape of fish due to structural failure. The analysis of recorded damage on the fish farm of Calheta during this study with data on sea conditions showed a significant positive correlation of damage on fish farms with wave height at most of the larger 24m diameter cages. The relevance of structural failure for escape events was supported by a massive escape event at the farming facility in Ribeira Brava in 2018, where the formation of large waves most likely led to the destruction of six net cages; resulting in the escape of over 1,000,000 individuals of *S. aurata.* However, some inconsistencies in the dataset, including large numbers of holes in the nets during periods with calm sea conditions indicate, that extreme weather scenarios may not be the only relevant cause for the escape of *S. aurata* from Madeiran fish farms. It is likely, that predatory species, such as *P.saltatrix* are responsible for this damage, or that the damage has another origin.

A newly tested camera system at the fish farm in Calheta was proven a suitable tool for the analysis of the species associated with the fish farming facilities with some limitations. However, the hypothesized relevance of predator attack for damage occurring in the net, mainly by *P. saltatrix*, could not be supported by the analysis of the video material filmed near the farming facility. The presence of top carnivorous species, other than *S. viridensis*, could not be confirmed, as the fish community around the farming facility appears to be dominated by *T. ovatus* and *S. maderensis.* However, other species, like *B. capriscus* and a sea turtle were sighted on video material and both species likely possess the ability to damage nets of a fish farm. Future research would most certainly benefit from the use of a fixed camera system, as such an approach would allow to gain an overview over the species community not only in the times when the farm operations are made. Further, a different timing of research may lead to different results, as the species communities around fish farms show a high degree of temporal variability around the year (Valle et al., 2007).

The analysis of 38 individuals of *S.aurata* collected in the harbour of Calheta did not show signs of gonad sexual maturity and the sampled specimens were considered immature. Consequently, it could not be shown, that there is an existing risk for a self-sustaining population of *S.aurata* in Madeira. Stomach content analysis suggests that escapee-seabream are capable of feeding on a wide range of prey, which includes mainly fish and commercial food pellets, but also seemingly random prey, as a terrestrial insect, that was found in the stomach of one individual. As the diet of *S. aurata* was dominated by fish (50.3% of the total weight of the prey), it cannot be precluded, that *S. aurata* does not represent a risk for the local environment. In terms of this study, we did not investigate, which species the seabream had ingested and whether these were caught by the seabream, or just opportunistically consumed discards from local fisheries.

This study represents a preliminary attempt in the investigation of the occurring escape events of farmed *S. aurata* around Madeira Island and related factors and consequences. Resulting from the limited course of this thesis, it was not possible to collect and analyse real-time data from the farming facilities. It was shown that structural failure most likely plays a major role in the escape of *S. aurata* and the species may resent a risk for the local environment. However, future research is urgent to further analyse the underlaying causes of escape events from offshore fish farming facilities and possible impacts in detail.

In the future, the risk of structural failure for the farms could be eliminated by building fish farms in areas which have a record of calm sea conditions; to prevent events, such as the collapse of several cages of the farming facility in Ribeira Brava. As technical improvements are currently made in offshore aquaculture (Jurado et al., 2018), such as the improvement of submersible cages (Milich & Drimer, 2019), it appears also possible, that offshore aquaculture may be operated with fewer failures in the future. To reduce the risks for the local environment resulting, from the presence of the non-native *S.aurata* in the wild, a possible measure would be to reduce the number of escapee *S. aurata*. As a study by Izquierdo-Gomez & Sanchez-Jerez (2016) showed, fish traps may be used to recapture a majority of escaped fish. Another study by Arechavala-Lopez et al. (2018b) evaluated the contribution of artisanal and recreational fisheries for the recapture of escaped farmed fish in the Mediterranean Sea. Such approaches may also be suitable for Madeira in case of an escape event.

References

Ahmed, M. S., 2011. Population dynamics and fisheries management of Gilthead sea bream, *Sparus aurata* (f. Sparidae) from Bardawil lagoon, North Sinai, Egypt. *Egypt J. Aquat. Biol. & Fish.,* 15(1), pp. 57-69.

Albins, M., 2013. Effects of invasive Pacific red lionfish *Pterois volitans* versus a native predator on Bahamian coral-reef fish communities. *Biol. Invasions,* Volume 15, pp. 29-43.

Alves, F. & Alves, C., 2002. Two new records of seabreams (Pisces: Sparidae) from the Madeira Archipelago. *Arquipélago. Life and Marine Science,* 19(A), pp. 107-111.

Andrade, C. & Gouveia, N., 2001. Evaluation of fish aggregation and space allocation around Baía d´Abra fishfarm, Madeira Island. *Serie Monografías del ICCM,* 4, pp. 56-62.

Andrade, C. & Gouveia, N., 2008. Ten years of aquaculture in Madeira Archipelago. In: C. Pham, R. Higgins, M. De Girolamo & E. Isidro, eds. *Proceedings of the International Workshop: Developing a Sustainable Aquaculture Industry in the Azores Arqquipélago.* s.l.:Life and Marine Scieces. Supplement 7: xiii + 81pp., pp. 30-32.

Arechavala-Lopez, P., Toledo-Guedes, K.; Izquierdo-Gomez, D., Šegvić-Bubić, T. & Sanchez-Jerez, P., 2018a. Implications of Sea Bream and Sea Bass Escapes for Sustainable Aquaculture Management: A Review of Interactions, Risks and Consequences. *Reviews in Fisheries Science & Auaculture,* 26(2), pp. 214–234.

Arechavala-Lopez, P., Izquierdo-Gomez, D., Forcada, A., Fernandez-Jover, D., Toledo-Guedes, K.,Valle, C. & P. Sanchez-Jerez, P., 2018b. Recapturing fish escapes from coastal farms in the western Mediterranean Sea: Insights for potential contingency plans. *Ocean & Coastal Management,* 151, pp. 69-76.

Arechavala-Lopez, P., Sanchez-Jerez, P., Bayle-Sempere, J.T., Uglem, I. & Mladineo, I. 2013. Reared fish, farmed escapees and wild fish stocks- a triangle of pathogen transmission of concern to Mediterranean aquaculture management. *Aquacult. Environ. Interact.,* 3, pp. 153-161.

Arechavala-Lopez, P., Uglem, I., Fernandez-Jover, D., Bayle-Sempere, J.T., Sanchez-Jerez, P., 2012. Post-escape dispersion of farmed seabream (*Sparus aurata L.*) and recaptures by local fisheries in the Western Mediterranean Sea. *Fish. Res.,* 121, pp. 126-135.

Arismendi, I., Soto, D., Penaluna, B., Jara, C., Leal, C. & Léon-Muñoz, J., 2009. Aquaculture, non-native salmonid invasions and associated declines of native fishes in Northern Patagonian lakes. *Freshwater Biol,* 54, pp. 1135–1147.

Austin, A., Chieff, A., Depardieu, J., Gratton, M., Holdaway, T., Lee, W.T., Libera, M., Naqiuddin, A., Yusof, F., Townsend, N. & Furth, M., 2019. *Novel concepts for offshore ocean farming.* Tacoma, United States, SNAME Maritime Convention.

Austin, B., 1993. Environmental Issues in the Control of Bacterial Diseases of Farmed Fish. In: *Environment and aquaculture in developing countries.* s.l.:s.n., pp. 237-251.

Aydin, M., 2018. Maximum length and age report of *Sparus aurata* (Linnaeus, 1758) in the Black Sea. *J Appl Ichthyol.,* 34, pp. 964-966.

Balart, E., Pérez-Urbiola, J.C., Campos-Dávila, L., Monteforte, M., Ortega-Rubio, A., 2009. On the first record of a potentially harmful fish, *Sparus aurata* in the Gulf of California. *Bio Invasions,* 11(3), pp. 547-550.

Ballester-Moltó, M., Sanchez-Jerez, P. & Aguado-Giménez, F., 2017. Consumption of particulate wastes derived from cage fish farming by aggregated wild fish. An experimental approach. *Marine Environmental Research,* 130, pp.166-173.

Bauchot, M.-L. & Hureau, J., 1986. Sparidae. In: P. Whitehead, et al. eds. *P.J.P. Whitehead, M.-L. Bauchot, J.-C. Hureau, J. Nielsen and E. Tortonese (eds.) Fishes of the north-eastern Atlantic and the Mediterranean.* Paris: UNESCO, pp. 883-907.

Bauchot, M.-L. & Hureau, J., 1990. Sparidae. In: J. Quero, et al. eds. *Check-list of the fishes of the eastern tropical Atlantic.* JNICT, Lisbon; SEI, Paris; and UNESCO, Paris.: CLOFETA, pp. 790-812.

Berstad, A. J., Tronstad, H., Sivertsen, S.-A. & Leite, E., 2005. Enhancement of Design Criteria for Fish Farm Facilities Including Operations. Halkidiki, Greece, 24th International Conference on Offshore Mechanics and Arctic Engineering: Volume 2.

Beweridge, M., 2004. *Cage Aquaculture.* 3 ed. s.l.:Blackwell Publishing Ltd.

Bjordal, A. & Skar, A., 1992. *Tagging of saithe (Pollachius virens L.) at a Norwegian fish farm: Preliminary results of migration.* Copenhagen, Denmark, International Council for the Exploration of the Sea, Other (ed.) ICES Demersal Fish Committee, pp. 67-87.

Bjørndal, T. & Guillen, J., 2017. Market integration between wild and farmed seabream and seabass in Spain. *Applied Economics,* 49(45), pp. 4567-4578.

Buxton, C. & Garratt, P., 1990. Alternative reproductive styles in seabreams (Pisces: Sparidae). *Environ. Biol. Fish.,* 28(1-4), pp. 113-124.

Cao, L., Wang, W., Yang, Y., Yang, C., Yuan, Z., Xiong, S. & Diana, J., 2007. Environmental Impact of Aquaculture and Countermeasures to Aquaculture Pollution in China. *Env Sci Pollut Res,* 14(7), pp. 452–462.

Casal, C., 2006. Global documentation of fish introductions: the growing crisis and. *Biol Invasions,* 8(1), pp. 3-11.

Castro, J., Santiago, J. & Santana-Ortega, A., 2002. A general theory on fish aggregation to floating objects: An alternative to the meeting point hypothesis. *Reviews in Fish Biology and Fisheries,* 11, pp. 255-277.

Chaoui, L., Hichem, K., Faure, E. & Quignard, J. P., 2006. Growth and reproduction of the gilthead seabream *Sparus aurata* in Mellah lagoon (north-eastern Algeria). *Scientia Marina,* 70(3).

Declerck, S., Louette, G., de Bie, T. & de Meester, L., 2002. Patterns of diet overlap between populations of non-indigenous and native fishes in shallow ponds. *J. Fish. Biol.,* 61, pp. 1182-1197.

Dempster, T., Fernandez-Jover,D., Sanchez-Jerez, P., Tuya, F., Bayle-Sempere, J., Boyra, A. & Haroun, R.J., 2005. Vertical variability of wild fish assemblages around sea-cage fish farms: implications for management. *Mar Ecol Prog.Ser.,* 304, pp. 15-29.

Dempster, T., Moe, H., Fredheim, A. & Sanchez-Jerez, P., 2007. *Escapes of marine fish from sea-cage aquaculture in the Mediterranean Sea: Status and Prevention. CIESM Workshop Monogr.,* 32, pp. 55-60.

Dempster, T., Sanchez-Jerez, P., Bayle-Sempere, J., Giménez-Casalduero, F. & Valle, C., 2002. Attraction of wild fish to sea-cage fish farms in the south-western Mediterranean Sea: spatial and short-term temporal variability. *Mar Ecol Prog Ser,* 242, pp. 237-252.

Dempster, T., Sanchez-Jerez, P., Bayle-Sempere, J. & Kingsford, M., 2004. Extensive aggregations of wild fish at coastal sea-cage fish farms. *Hydrobiologia,* 525, pp. 245-248.

Dimitriou, E., Katselis, G., Moutopoulos, D. & Akovitiotis, C., 2007. Possible influence of reared gilthead sea bream (*Sparus aurata*, L.) on wild stocks in the area of the Messolonghi lagoon (Ionian Sea, Greece). *Aquaculture Research,* 38, pp. 398-408 .

Edelist, D., Rilov, G., Golani, D., Carlton, J.T. & Spanier, E. 2013. Restructuring the Sea: profound shifts in the world's most invaded marine ecosystem. *Diver. Dist.,* 19(1), pp. 69–77 .

FAO, 2016. *Fisheries and aquaculture software. FishStatJ – software for fishery statistical time series. In: FAO Fisheries and Aquaculture Department [online]. Rome. Updated 21 July 2016.* [Cited 23 September 2019]

FAO, 2018. *The State of World Fisheries and Aquaculture 2018 - Meeting the sustainable development goals..* Rome, Licence: CC BY-NC-SA 3.0 IGO.

FAO, 2019 Cultured Aquatic Species Information Programme. Sparus aurata. Cultured Aquatic Species Information Programme. Text by Colloca, F.; Cerasi, S. In: *FAO Fisheries and Aquaculture Department* [online]. Rome. Updated 8 February 2005. [Cited 27 September 2019].

Fiske, P., Lund, R. & Hansen, L., 2005. Identifying fish farm escapees. In: S. Cadrin, K. Friedland & J. Waldman, eds. *Stock Identification Methods. Appplications in Fishery Science.* Amsterdam: Elsevier, pp. 659–680.

Friedlander, A. M., Ballesteros, E., Clemente, S. & Gonçalves, E. J., Estep, A., Rose, P. & Sala, E., 2017. Contrasts in the marine ecosystem of two Macaronesian islands: A comparison between the remote Selvagens Reserve and Madeira Island. *PLOS ONE,* 12(11).

Froese, R. & Pauly, D., 2019. *FishBase.* [Online] Available at: www.fishbase.org, version (04/2019) [Accessed April 2019].

Froese, R., Winker, H., Coro, G.,Demirel, N., Tsikliras, A.C., Dimarchopoulou, D., Scarcella, G., Quaas, M. & Matz-Lück, N., 2018. Status and rebuilding of European fisheries. *Marine Policy,* 93, pp. 159-170.

Gentry, R.C., Lester, S.E., Kappel, C.V., White, C., Bell, T.W., Stevens, J. & Gaines, S.D. 2017. Offshore aquaculture: Spatial planning principles for sustainable development. *Ecology and Evolution,* 7, pp. 733–743 .

Glaropoulos, A., Papadakis, V., Papadakis, I. & Kentouri, M., 2012. Escape-related behavior and coping ability of sea bream due to food supply and biofouling presence. *Aquacult Int,* 20, pp. 965–979.

Gray, A.E, Williams, I.D., Stamoulis, K.A., Boland, R.C., Lino, K.C., Hauk, B.B., Leonard, J.C., Rooney, J.J., Asher, J.M., Lopes, K.H. Jr. & Kosaki, R.K., 2016. Comparison of Reef Fish Survey Data Gathered by Open and Closed Circuit SCUBA Divers Reveals Differences in Areas With Higher Fishing Pressure. *PLOS ONE,* 11(12).

Güçlüsoy, H. & Savas., Y., 2003. Interaction between monk seals *Monachus monachus* (Hermann, 1779) and marine fish farms in the Turkish Aegean and management of the problem. *Aquacult. Res.,* 34, pp. 777–783.

Guillen, J., Asche, F., Carvalho, N., Fernández Polanco, J.M., Llorente, I., Nielsen, R., Nielsen, M. & Villasante, S., 2019. Aquaculture subsidies in the European Union: Evolution, impact and future potential for growth. *Marine Policy,* 104, pp. 19-28.

Hansen, L.A., Dale, T., Damsgård, B.,Uglem, I., Aas, K. & Bjørn, P-A., 2009. Escape-related behaviour of Atlantic cod, *Gadus morhua* L., in a simulated farm situation. *Aquac Res ,* 40, pp. 26-34.

Hermida, M. & Delgado, J., 2016. High trophic level and low diversity: Would Madeira benefit from fishing down?. *Marine Policy,* 73, pp. 130-137.

Holden, M. J. & Raitt, D. F. S., 1974. *Manual of fisheries science.* Rome : Food and Agriculture Organization of the United Nations.

Holmer, M., 2010. Environmental issues of fish farming in offshore waters: perspectives, concerns and research needs. *Aquacult Environ Interact,* 1, pp. 57-70.

Holubová, M., Čech, M., Vašek, M. & Peterka, J., 2019. On the use of a visual census in surveying fish communities in lentic water bodies. *Ecological Indicators,* 105, pp. 1-5.

Høy, E., Volent, Z., Moe-Føre, H. & Dempster, T., 2012. Loads applied to aquaculture nets by the biting behaviour of Atlantic cod (*Gadus morhua*). *Aquacultural Engineering,* 47, pp. 60-63.

Huguenin, J., 1997. The design, operations and economics of cage culture systems. *Aquacultural Engineering,* 16(3), pp. 167-203.

Izquierdo-Gomez, D. & Sanchez-Jerez, P., 2016. Management of fish escapes from Mediterranean Sea cage aquaculture through artisanal fisheries. *Ocean & Coastal Management,* 122, pp. 57-63.

Jackson, D, Drumm, A., McEvoy, S., Jensen, Ø., Mendiola, D., Gabiña, G., Borg, J.A., Papageorgiou, N., Karakassis, Y. & Black, K.D., 2015. A pan-European valuation of the extent, causes and cost of escape events from sea cage fish farming. *Aquaculture,* 436, pp. 21-26.

Jackson, J.B.C., Kirby, M.X., Berger, W.H., Bjorndal, K.A., Botsford, L.W., Bourque, B.J., Bradbury, R.H., Cooke, R., Erlandson, J., Estes, J.A., Hughes, T.P, Kidwell, S., Lange, C.B., Lenihan, H.S., Pandolfi, J.M., Peterson, C.H., Steneck, R.S., Tegner, M.J. & Warner, R.R., 2001. Historical Overfishing and the Recent Collapse of Coastal Ecosystems. *Science,* 293(5530), pp. 629-637.

Jensen, Ø., 2006. *Assessment of escape causes from Norwegian fish farms during two storm periods in January 2006,* s.l.: SINTEF Report SFH80 A066056, (ISBN 82-14-03953-8).

Jensen, Ø., Dempster, T, Thorstad, T.E.B., Uglem, I. & Fredheim, A., 2010. Escapes of fishes from Norwegian sea-cage aquaculture: causes, consequences and prevention. *Aquacult Environ Interact,* 1, pp. 71-83.

Jurado, A., Sánchez, P., Armesto, J.A., Guanche, R., Ondiviela, B. & Juanes, J.A., 2018. *Experimental and Numerical Modelling of an Offshore Aquaculture Cage for Open Ocean Waters.* Madrid, Spain, Proceedings of the ASME 2018 37th International Conference on Ocean, Offshore and Arctic Engineering, 7A: Ocean Engineering..

Lee, C.-W., Kim, Y.-B., Lee, G.-H.,Choe, M.-Y., Lee, M.-K. & Koo, K.-Y., 2008. Dynamic simulation of a fish cage system subjected to currents and waves. *Ocean Engineering,* 35(14-15), pp. 1521-1532.

Liao, Y., Chen, L. & Shao, K., 2010. The predatory Atlantic red drum, *Sciaenops ocellatus*, has invaded the western Taiwanese coast in the Indo-West Pacific. *Biol Invasions,* 12, pp. 1961–1965.

Lindfield, S. J., Harvey, E. S., L. McIlwain, J. L. & Halford, A. R., 2014. Silent fish surveys: bubble-free diving highlights inaccuracies associated with SCUBA-based surveys in heavily fished areas. *Methods in Ecology and Evolution,* 5, pp. 1061-1069.

McCord, C. & Westneat, M., 2016. Evolutionary Patterns of Shape and Functional Diversification in the Skull and Jaw Musculature of Triggerfishes (Teleostei: Balistidae). Journal of Morphology*,* 277, pp. 737-752.

McGinnity, P., Prodöhl, P., Ferguson, A., Hynes, R., ó Maoiléidigh, N., Baker, N., Cotter, D., O'Hea, B., Cooke, D., Rogan, G., Taggart, J. & Cross, T., 2003. Fitness reduction and potential extinction of wild populations of Atlantic salmon, *Salmo salar*, as a result of interactions with escaped farm salmon. *Proc. R. Soc. Lond. B ,* 270, pp. 2443–2450.

Milich, M. & Drimer, N., 2019. Design and Analysis of an Innovative Concept for Submerging Open-Sea Aquaculture System. *EEE Journal of Oceanic Engineering,* 44(3), pp. 707-718.

Moe, H., Dempster, T., Magne Sunde, L., Winther, U. & Fredheim, A., 2007. Technological solutions and operational measu res to prevent escapes of Atlantic cod (*Gadus morhua*) from sea cages. *Aquaculture Research,* 38, pp. 91-99.

Moe, H., Fredheim, A. & Hopperstad, O. S., 2010. Structural analysis of aquaculture net cages in current. *Journal of Fluids and Structures,* 26(3), pp. 503-516.

Moe, H., Gaarder, R. H., Olsen, A. & Hoppperstad, O. S., 2009. Resistance of aquaculture net cage materials to biting by Atlantic Cod (*Gadus morhua*). *Aquacultural Engineering,* 40(3), pp. 126-134.

Moreno, G., Dagorn, L., Capello, M., Lopez, J., Filmalter, J., Forget, F., Sancristobal, I. & Holland, K., 2016. Fish aggregating devices (FADs) as scientific platforms. *Fisheries Research,* 178, pp. 122-129.

NAS, 2003. *NS 9415 Marine fish farms – requirements for design dimensjoning, production, installation and operation.* 1322 Lysaker, Norway: Standards Norway, Pronorm AS Postboks 252.

Oliveira, P., 2008. Who values what in a tourism destination? The case of Madeira Island. *Tourism Economics,* 14(1), pp. 155-168.

Papadakis, I.E., Papadakis, V., Glaropoulos, A. L. F. & Kentouri, M., 2013. Escape-related behavior of juvenile gilthead sea bream (*Sparus aurata*) versus rearing density in experimental conditions. *Journal of Biological Research-Thessaloniki ,* 20, pp. 208-2016.

Papadakis, V., Papadakis, I.E., Lamprianidou, F., Glaropoulos, A. & Kentouri, M., 2012. A computer-vision system and methodology for the analysis of fish behavior. *Aquacultural Engineering,* 46, pp. 53-59.

Pérez, O., Telfer, T. & Ross, L., 2003. On the calculation of wave climate for offshore cage culture site selection: a case study in Tenerife (Canary Islands). *Aquacultural Engineering,* 29, pp. 1-21.

Pinheiro, H. T., Goodbody-Gringley, G., Jessup, M.E., Shepherd, B., Chequer, A.D. & Rocha, L.A., 2015. Upper and lower mesophotic coral reef fish communities evaluated by underwater visual censuses in two Caribbean locations. *Coral Reefs,* 35(1), pp. 139-151.

Pita, C., Gamito, S. & Erzini, K., 2002. Feeding habits of the gilthead seabream (*Sparus aurata*) from the Ria Formosa (southern Portugal), as compared to the black seabream (*Spondyliosoma cantharus*) and the annular seabram (*Diplodus annularis*). *J. Appl. Ichtyol.,* 18, pp. 81-86.

Png-Gonzalez, L., Andrade, C., Abramic, A. & Nogueira, N., 2019. *Analysis of the aquaculture industry in Macaronesia under MSFD,* s.l.: Report prepared as part of PLASMAR Project (co-financed by ERDF as part of POMAC 2014-2020).

Polanco, J. & Bjorndal, T., 2017. Aquaculture Diversification in Europe: The Kingdom of Spain and the Kingdom of Norway. In: B. Harvey, et al. eds. *Planning for aquaculture diversification: the importance of climate change and other drivers.* Rome: FAO Fisheries and Aquaculture Proceedings No. 47, pp. 37-49.

Rana, K., 2005. *Regional review on aquaculture development 6. Western-European Region.* 1 ed. Rome: Food and Agriculture Organisation of the United Nations, FAO Fisheries Circular No.1017/6.

Read, P. & Fernandes, T., 2003. Management of environmental impacts of marine aquaculture in Europe. *Aquaculture,* 226(1-4), pp. 139-163.

Riera, R., Pérez, O., Cromey, C., Rodríguez, M., Ramos, E., Álvarez, O., Domínguez, J., Monterroso, Ó. & Tuya, F.,2017. MACAROMOD: A tool to model particulate waste dispersion and benthic impact from offshore sea-cage aquaculture in the Macaronesian region. *Ecological Modelling,* 361, pp. 122-134.

Sanchez-Jerez, P., Fernandez-Jover, D., Bayle-Sempere, J., Valle, C., Dempster, T., Tuya, F. & Juanes, F., 2008. Interactions between bluefish *Pomatomus saltatrix* (L.) and coastal sea-cage farms in the Mediterranean Sea. *Aquaculture,* 282, pp. 61-67.

Sarà, G., Dean, J.M., D'Amato, D., Buscaino, G., Oliveri, A., Genovese, S., Ferro, S., Buffa, G., Lo Martire, M. & Mazzola, S., 2007. Effect of boat noise on the behaviour of bluefin tuna *Thunnus thynnus* in the Mediterranean Sea. *Mar Ecol Prog Ser,* 331, pp. 243-253.

Sbragaglia, V., Morroni, L., Bramanti, L., Weitzmann, B., Arlinghaus, R. & Azzurro, E., 2018. Spearfishing modulates flight initiation distance of fishes: the effects of protection, individual size, and bearing a speargun. *ICES Journal of Marine Science,* 75(5), pp. 1779-1789.

Science for Environment Policy, 2015. *Sustainable Aquaculture.* Bristol, Future Brief 11. Brief produced for the European Commission DG Environment by the Science Communication Unit, UWE.

Tancionia, L., Mariani, S., Maccaroni, A., Mariani, A., Massa, F., Scardi, M. & Cataudella, S. 2003. Locality-specific variation in the feeding of *Sparus aurata* L.: evidence from two Mediterranean lagoon systems. *Estuarine, Coastal and Shelf Science,* 57, pp. 469-474.

Thorvaldsen, T., Holmen, I. M. & Moe, H. K., 2015. The escape of fish from Norwegian fish farms: Causes, risks and the influence of organisational aspects. *Marine Policy,* 55, pp. 33-38.

Toledo-Guedes, K., Sanchez-Jerez, P., Benjumea, M. & Brito, A., 2014. Farming-up coastal fish assemblages through a massive aquaculture escape event. *Marine Environmental Research,* 98, pp. 86-95.

Tomassetti, P., Gennaro, P., Lattanzi, L., Mercatali, I., Persia, E., Vani, D. & Porrello, S., 2016. Benthic community response to sediment organic enrichment by Mediterranean fish farms: Case studies. *Aquaculture,* 450, pp. 262-272.

Trujillo, P., Piroddi, C. & Jacquet, J., 2012. Fish farms at sea: the ground truth from Google Earth. *PLoS One,* 7(2), p. e30546.

Tuya, F., Sanchez-Jerez, P., Dempster, T., Boyra, A. & Haroun, R.J., 2006. Changes in demersal wild fish aggregations beneath a sea-cage fish farm after the cessation of farming. *Journal of Fish Biology,* 69, pp. 682-697.

Ungaro, 2008. *Field manual on macroscopic identification of maturity stages for the Mediterranean fishery ressources,* s.l.: GCP/RER/ITA/MSM-TD-21. MedSudMed Technical Documents No 21: 34.

Valle, C., Bayle-Sempere, J.T., Dempster, T., Sanchez-Jerez, P. & Giménez-Casalduero, F., 2007. Temporal variability of wild fish assemblages associated with a sea-cage fish farm in the south-western Mediterranean Sea.. *Estuar. Coast. Shelf Sci.,* 72(1-2), pp. 299–307.

Welcome, R. L., 1988. International introductions of inland aquatic species.. *FAO Fisheries Technical Paper No. 294. Food and Agriculture Organization of the United Nations, Rome, Italy,* 318.

Wu, R., 1995. The environmental impact of marine fish culture: Towards a sustainable future. *Marine Pollution Bulletin,* 31(4-12), pp. 159-166.

Wu, R., Lam, K.S., MacKay, D.W., Lau, T.C. & Yam, V.1994. Impact of marine fish farming on water quality and bottom sediment: A case study in the sub-tropical environment. *Marine Environmental Research,* 38(2), pp. 115-145.

Zarco-Perello, S. & Enríquez, S., 2019. Remote underwater video reveals higher fish diversity and abundance in seagrass meadows, and habitat differences in trophic interactions. *Scientific Reports,* 9(6596).

Appendix

Appendix I Maximum and significant wave height measurements

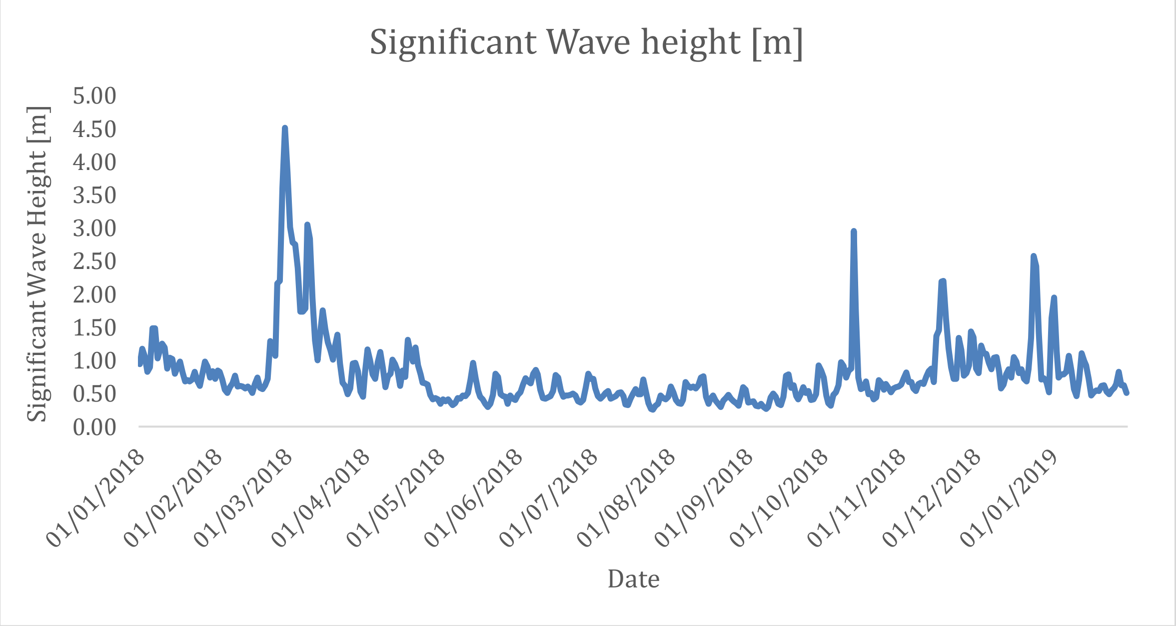


Figure 2.5 Line chart of significant wave height in the period from January 2018-January 2019; data provided by IPMA derived from an oceanographic buoy near Funchal

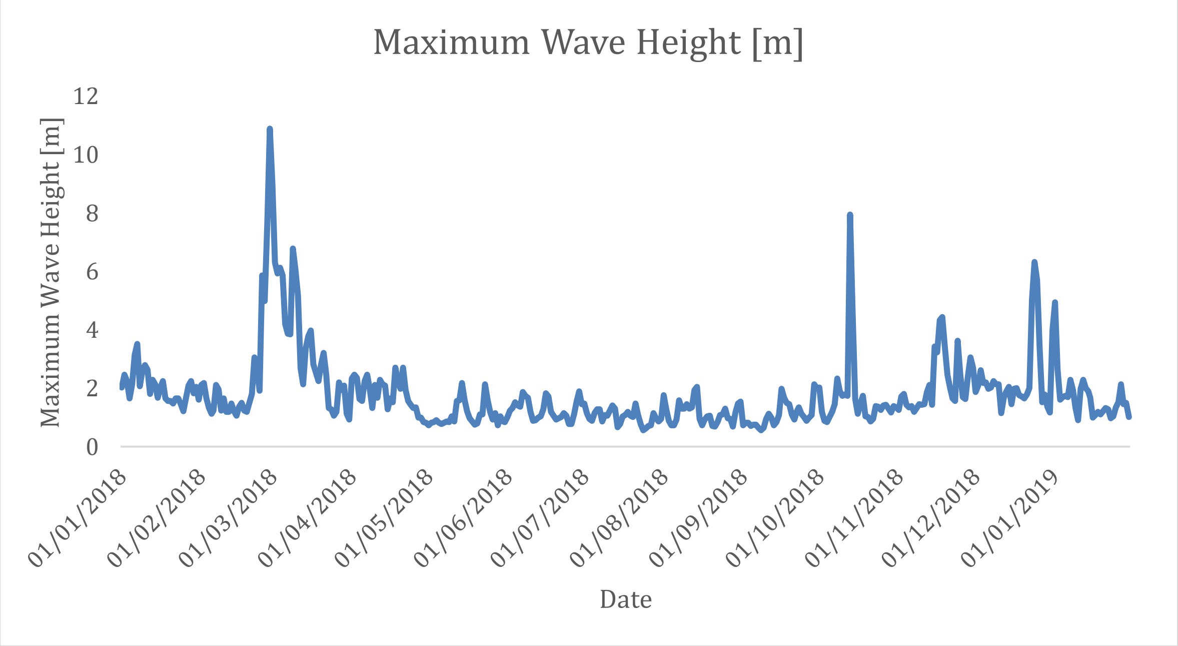


Figure 2.6 Line chart of maximum wave height in the period from January 2018-January 2019; data provided by IPMA derived from an oceanographic buoy near Funchal

Appendix II Maximum wind speed near Funchal, Madeira

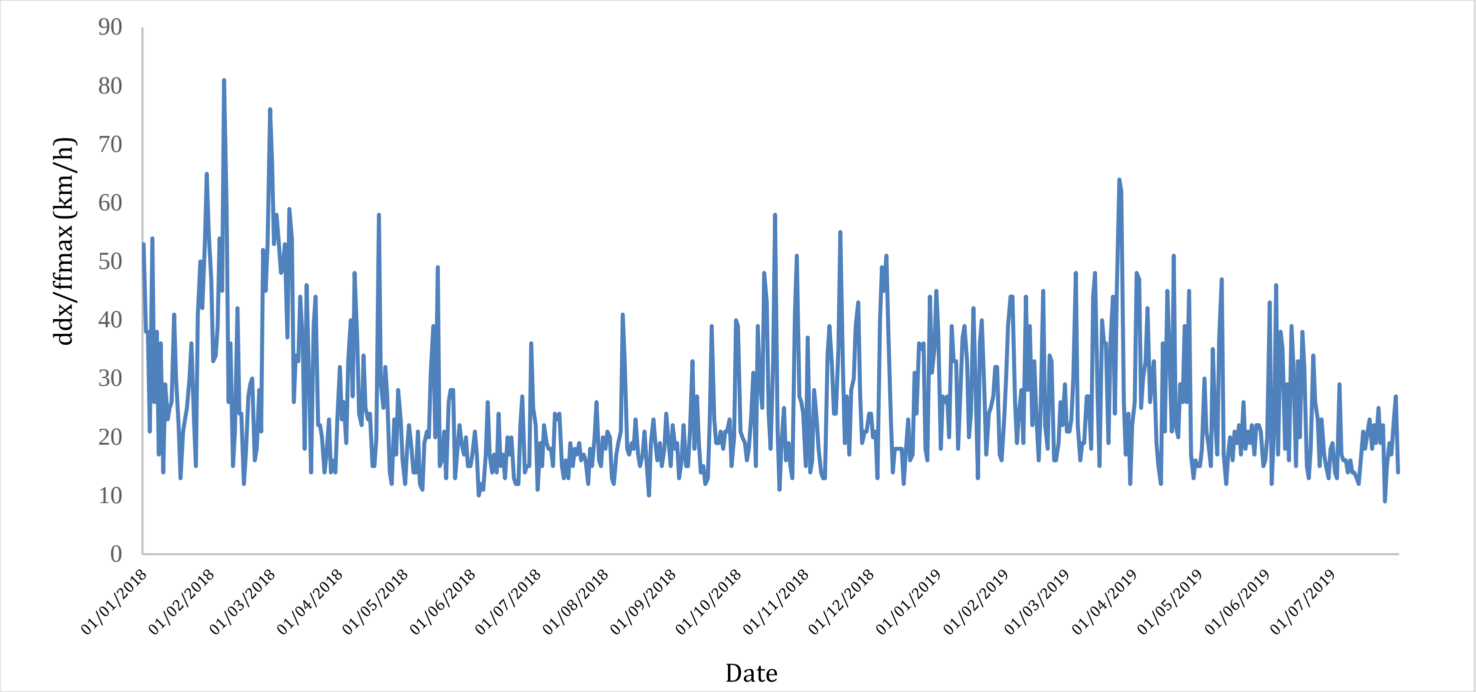


Figure 2.7 Line chart of maximum wind speeds (ddx/ffmax in km/h) recorded at station 522, Funchal by IPMA

Appendix III Scatterplots of significant and maximum wave height (m) versus the number of holes in the net at Calheta fish farm (Cage 1-4: 12.7m diameter, Cage 6-10: 24m diameter)

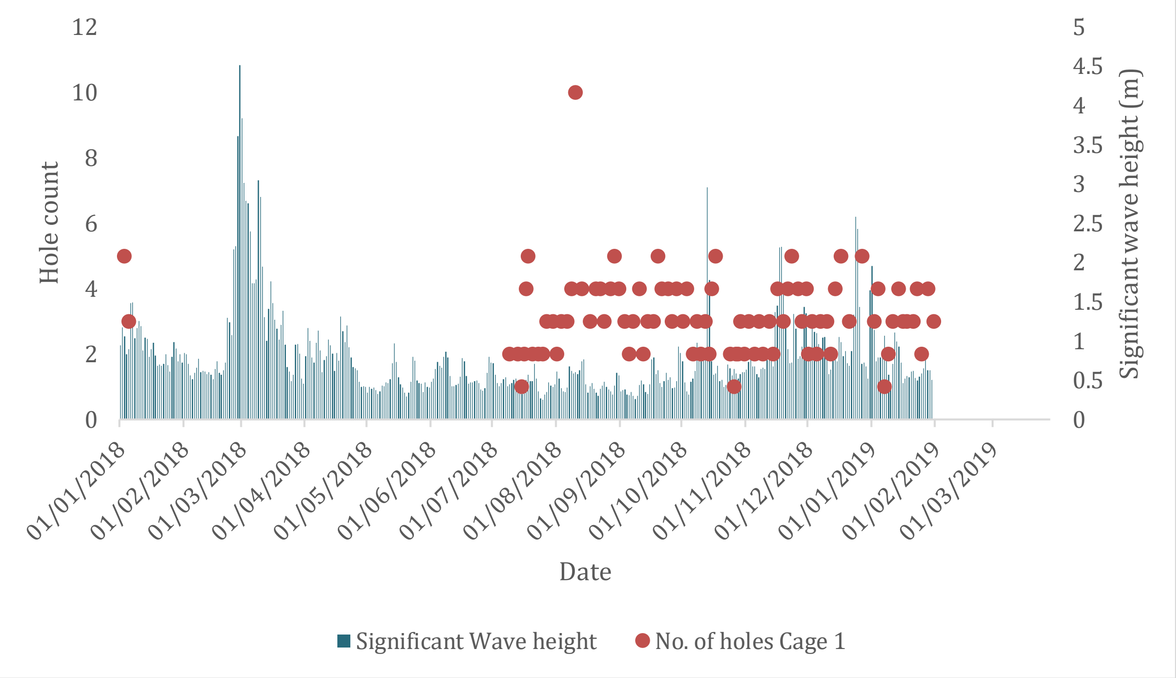


Figure 2.8 Scatterplot of the significant wave height (m) plotted versus the number of holes counted at the fish farm in Calheta from January 2018 to March 2019 for cage 1

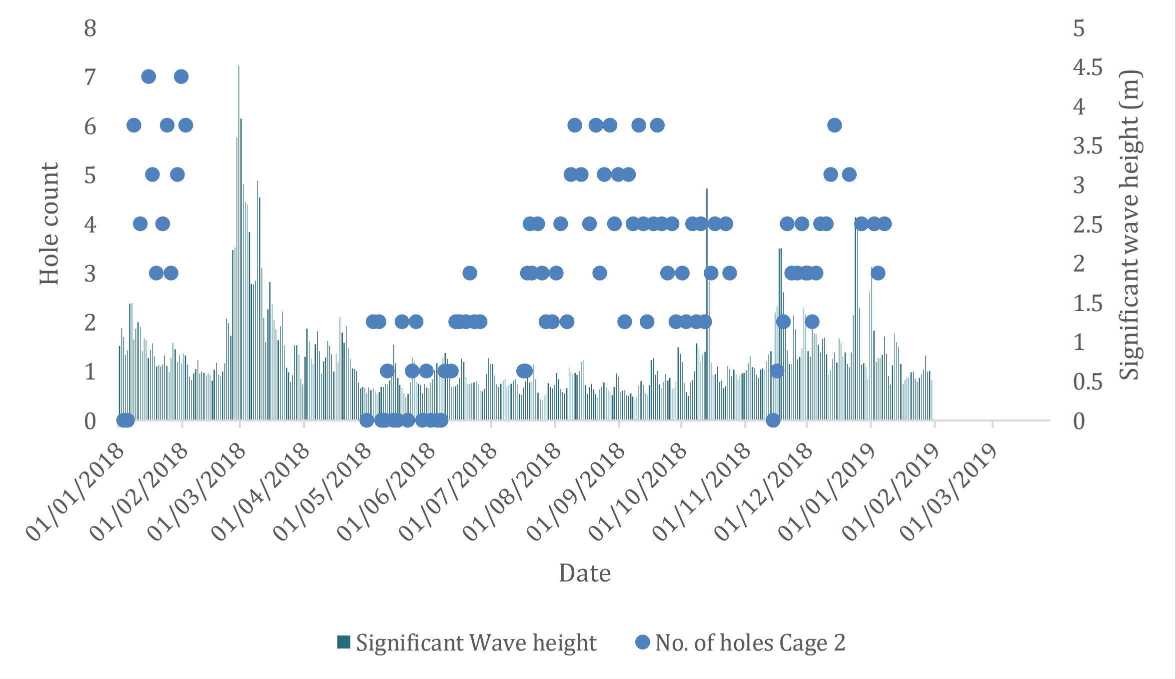


Figure 2.9 Scatterplot of the significant wave height (m) plotted versus the number of holes counted at the fish farm in Calheta from January 2018 to March 2019 for cage 2

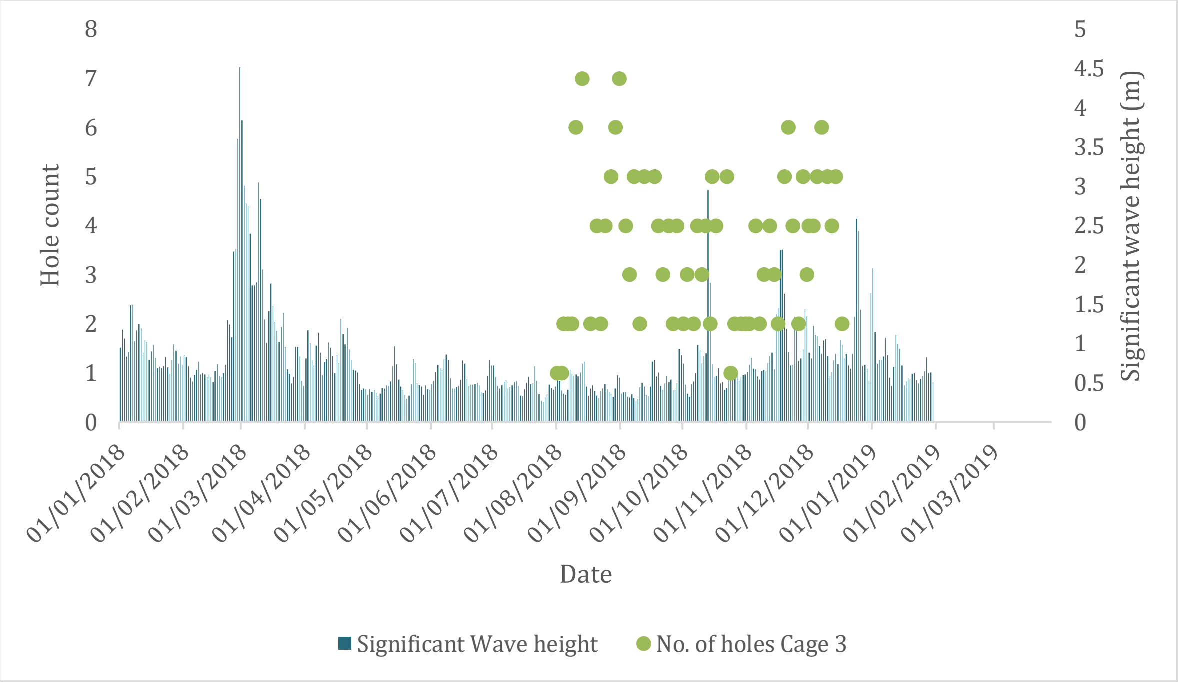


Figure 2.10 Scatterplot of the significant wave height (m) plotted versus the number of holes counted at the fish farm in Calheta from January 2018 to March 2019 for cage 3

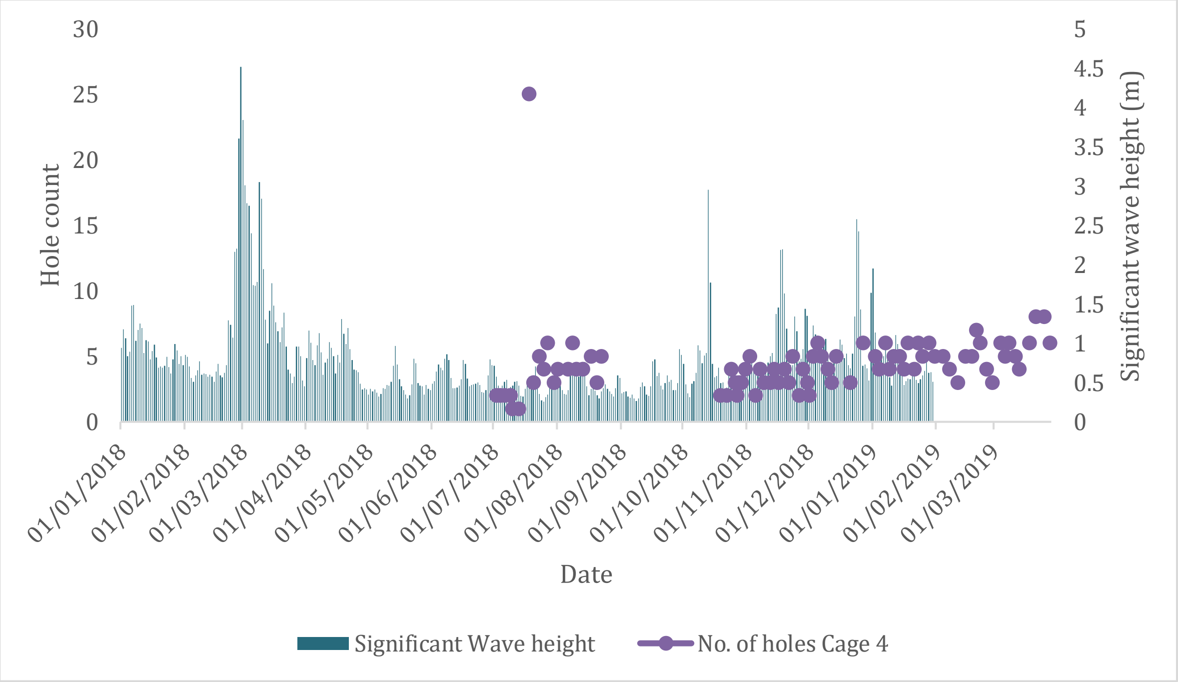


Figure 2.11 Scatterplot of the significant wave height (m) plotted versus the number of holes counted at the fish farm in Calheta from January 2018 to March 2019 for cage 4

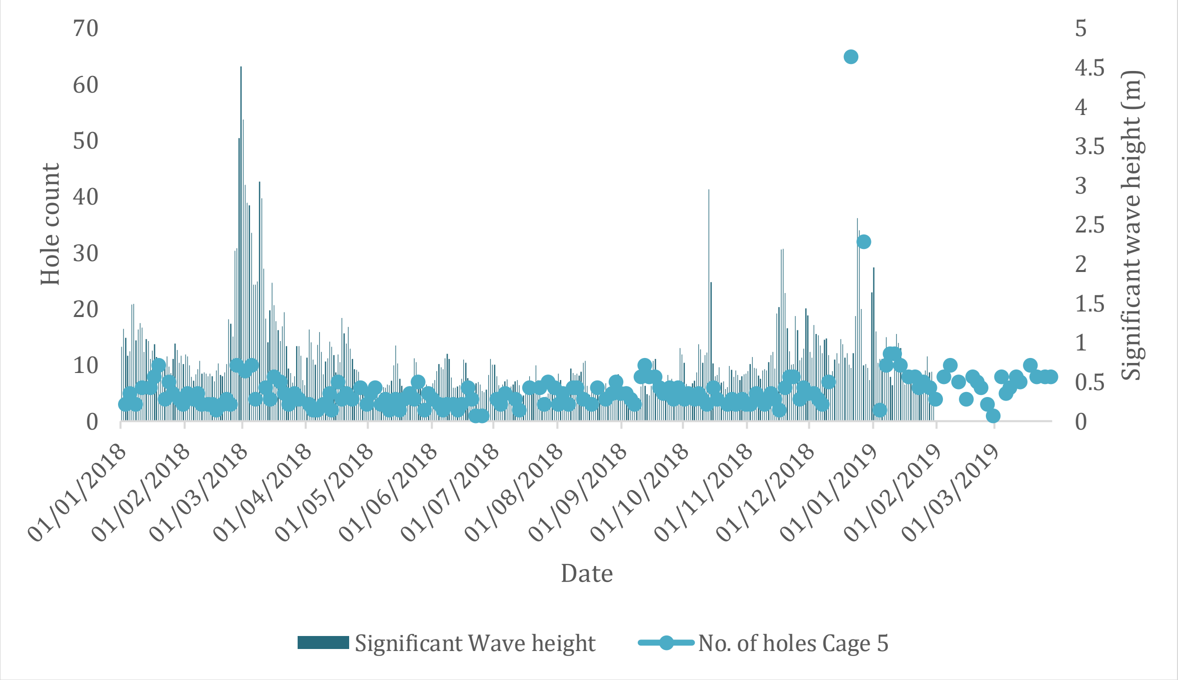


Figure 2.12 Scatterplot of the significant wave height (m) plotted versus the number of holes counted at the fish farm in Calheta from January 2018 to March 2019 for cage 5

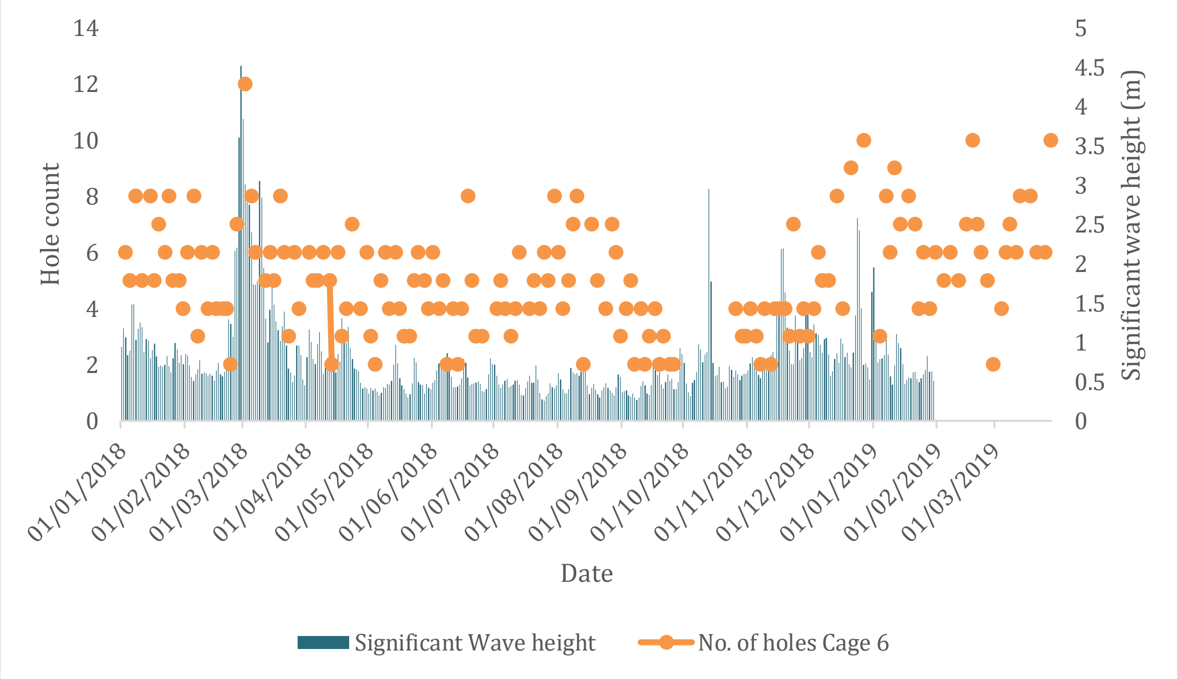


Figure 2.13 Scatterplot of the significant wave height (m) plotted versus the number of holes counted at the fish farm in Calheta from January 2018 to March 2019 for cage 6

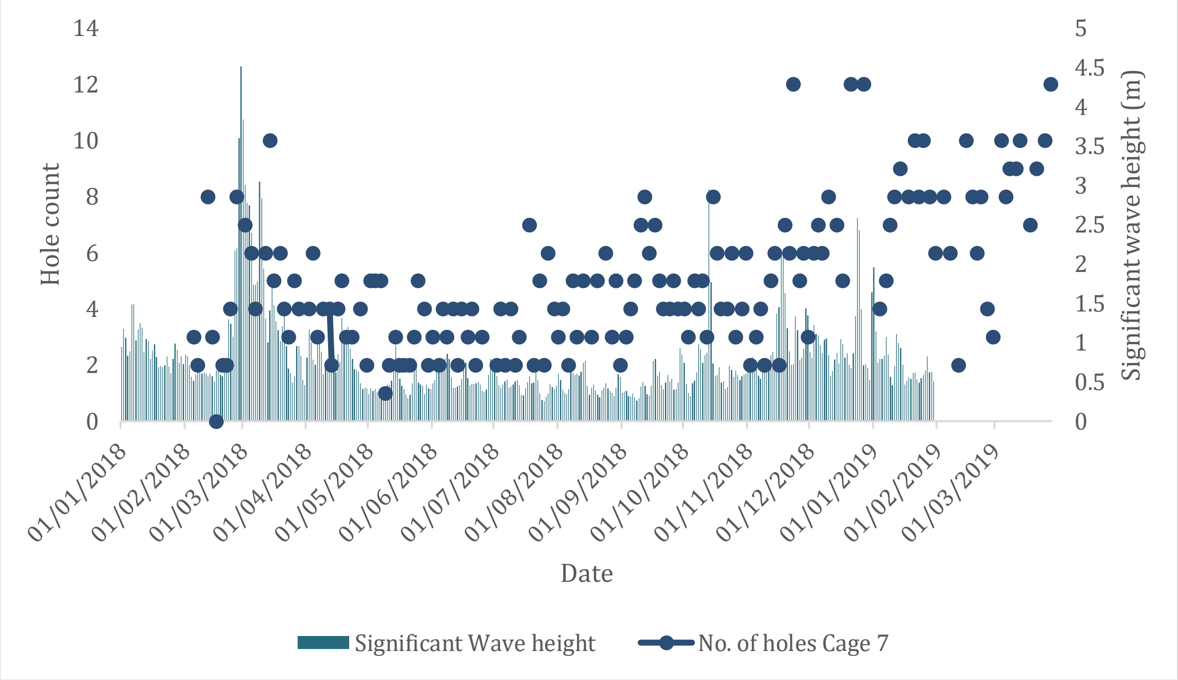


Figure 2.14 Scatterplot of the significant wave height (m) plotted versus the number of holes counted at the fish farm in Calheta from January 2018 to March 2019 for cage 7

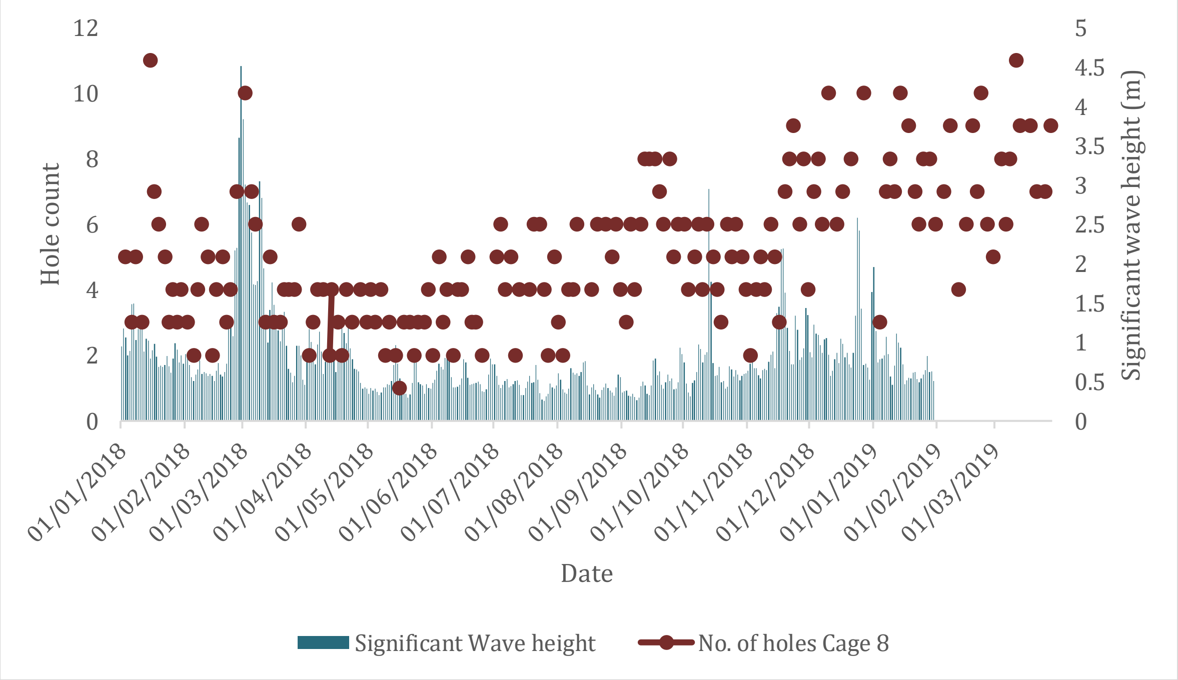


Figure 2.15 Scatterplot of the significant wave height (m) plotted versus the number of holes counted at the fish farm in Calheta from January 2018 to March 2019 for cage 8

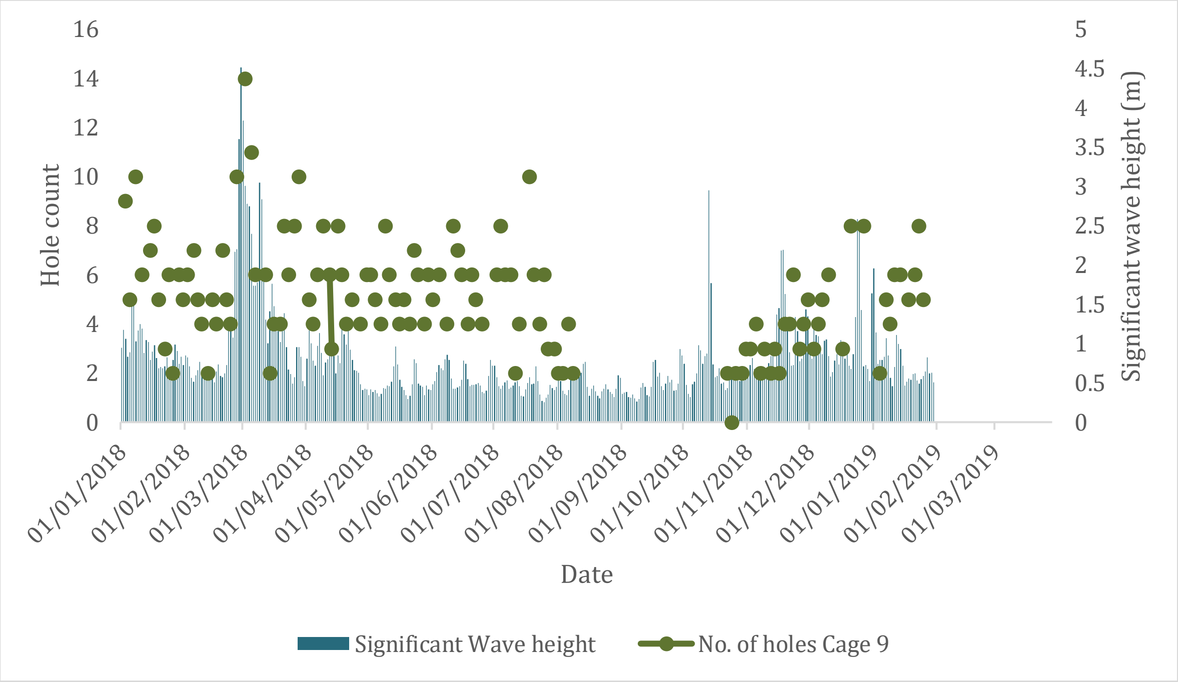


Figure 2.16 Scatterplot of the significant wave height (m) plotted versus the number of holes counted at the fish farm in Calheta from January 2018 to March 2019 for cage 9

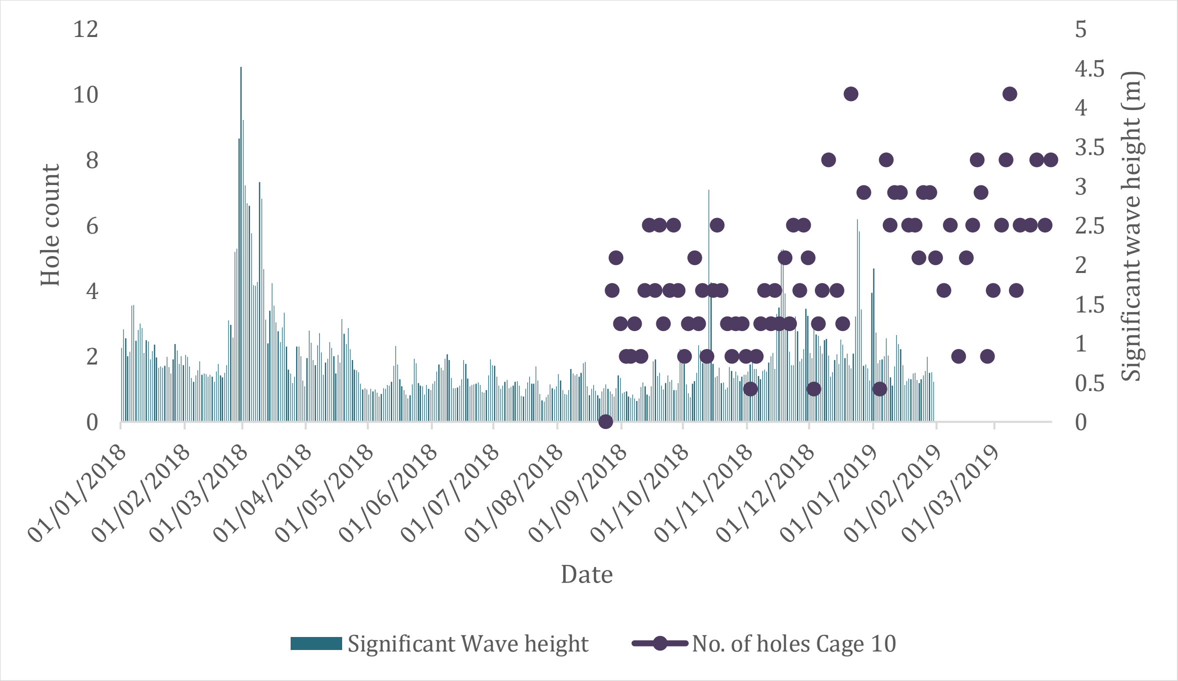


Figure 2.17 Scatterplot of the significant wave height (m) plotted versus the number of holes counted at the fish farm in Calheta from January 2018 to March 2019 for cage 10

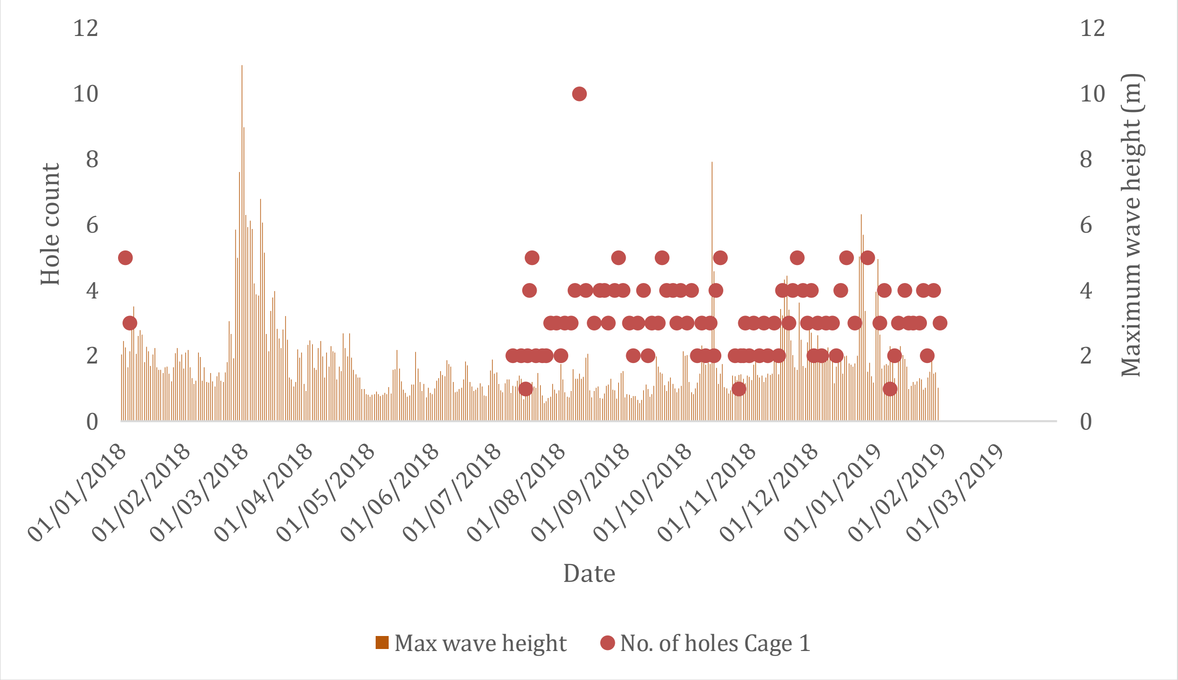


Figure 2.18 Scatterplot of the maximum wave height (m) plotted versus the number of holes counted at the fish farm in Calheta from January 2018 to March 2019 for cage 1

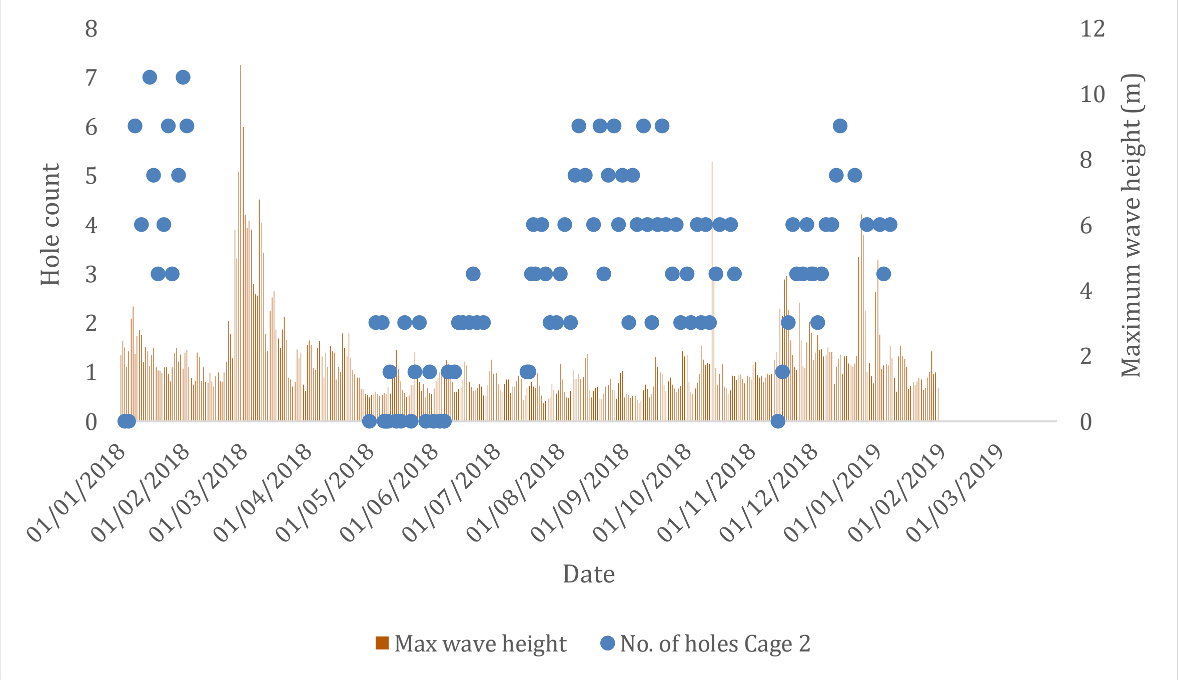


Figure 2.19 Scatterplot of the maximum wave height (m) plotted versus the number of holes counted at the fish farm in Calheta from January 2018 to March 2019 for cage 2

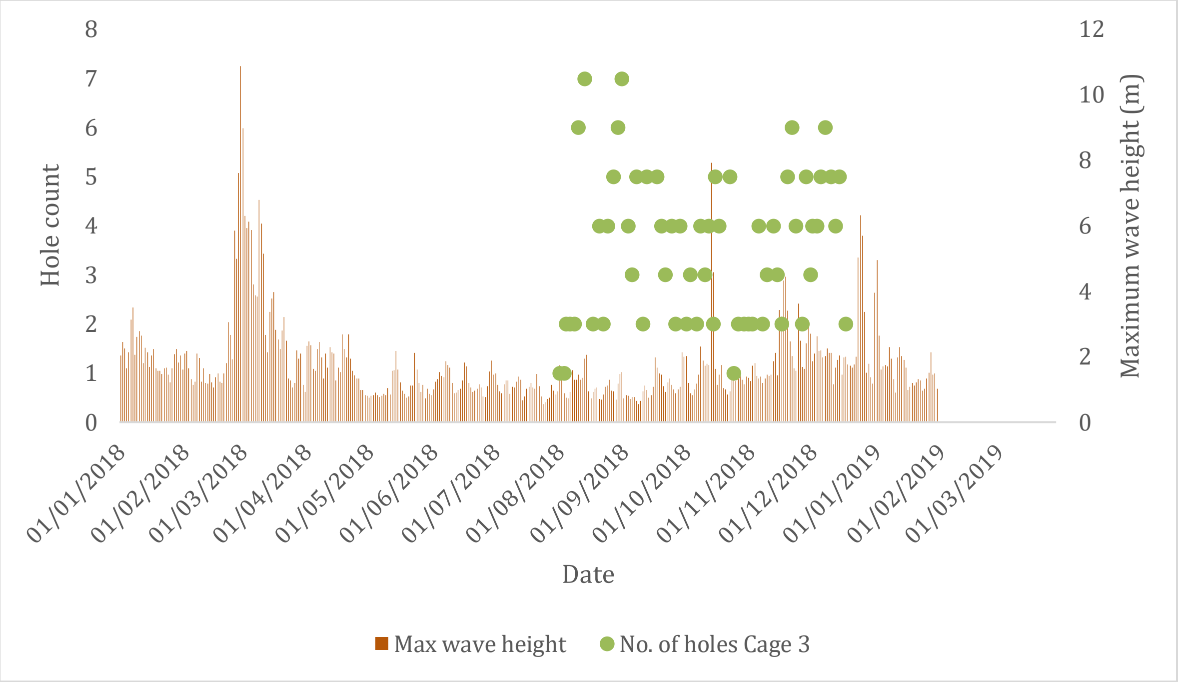


Figure 2.20 Scatterplot of the maximum wave height (m) plotted versus the number of holes counted at the fish farm in Calheta from January 2018 to March 2019 for cage 3

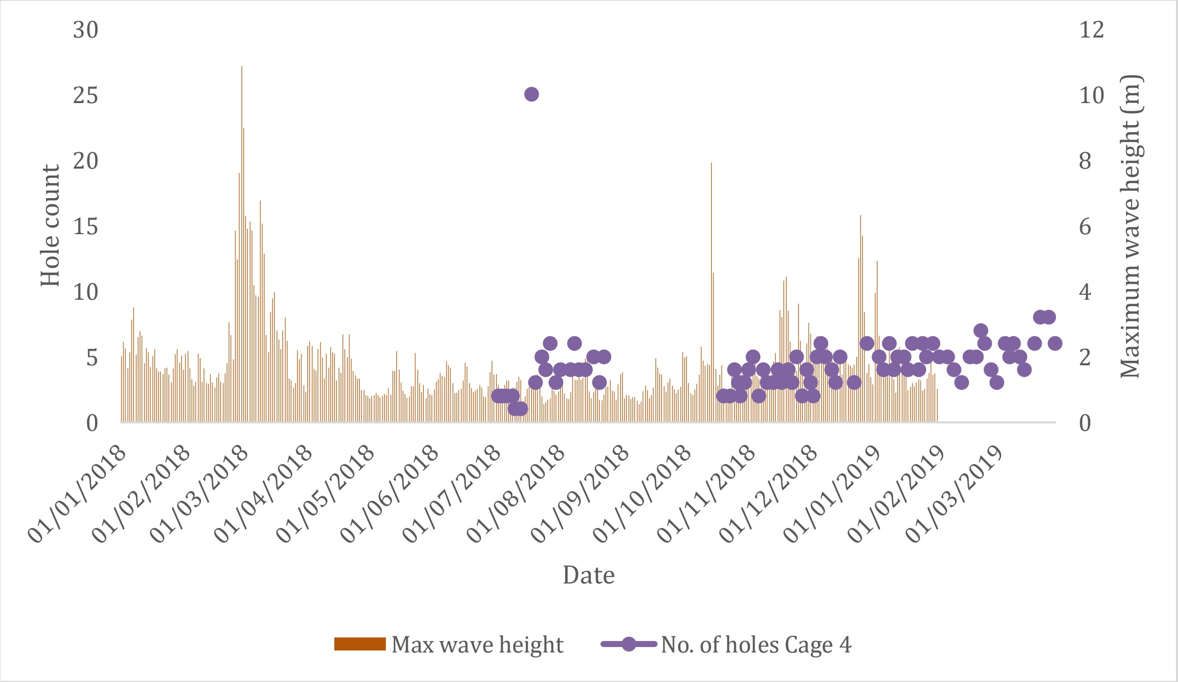


Figure 2.21 Scatterplot of the maximum wave height (m) plotted versus the number of holes counted at the fish farm in Calheta from January 2018 to March 2019 for cage 4

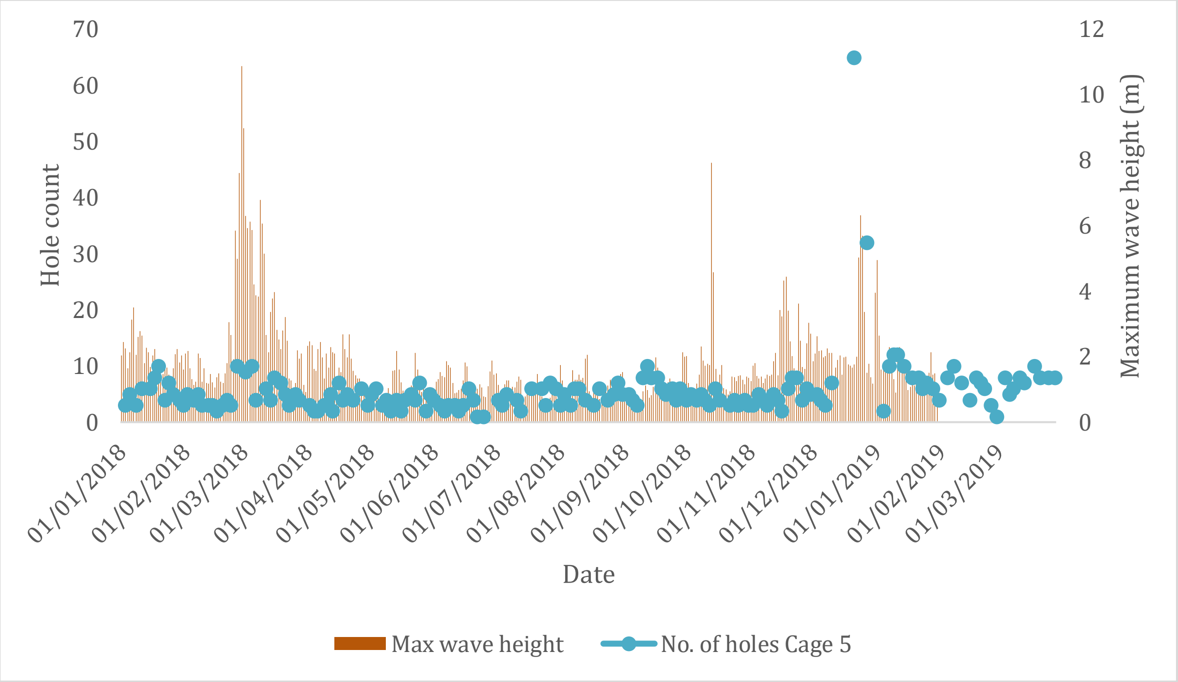


Figure 2.22 Scatterplot of the maximum wave height (m) plotted versus the number of holes counted at the fish farm in Calheta from January 2018 to March 2019 for cage 5

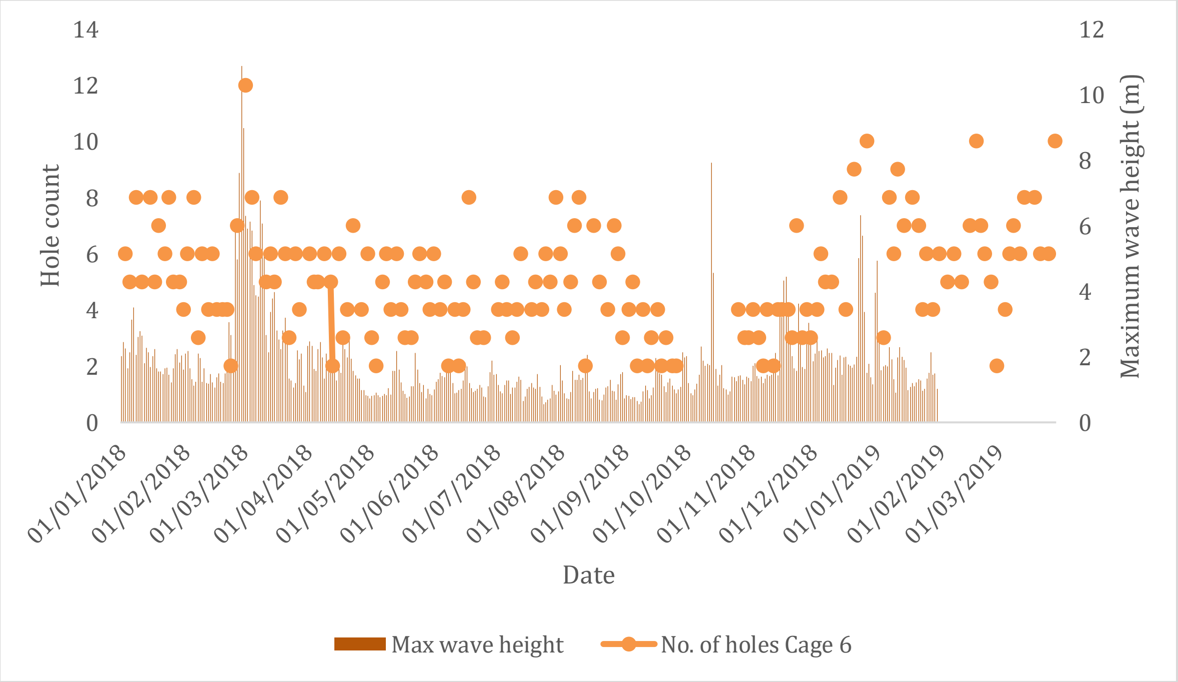


Figure 2.23 Scatterplot of the maximum wave height (m) plotted versus the number of holes counted at the fish farm in Calheta from January 2018 to March 2019 for cage 6

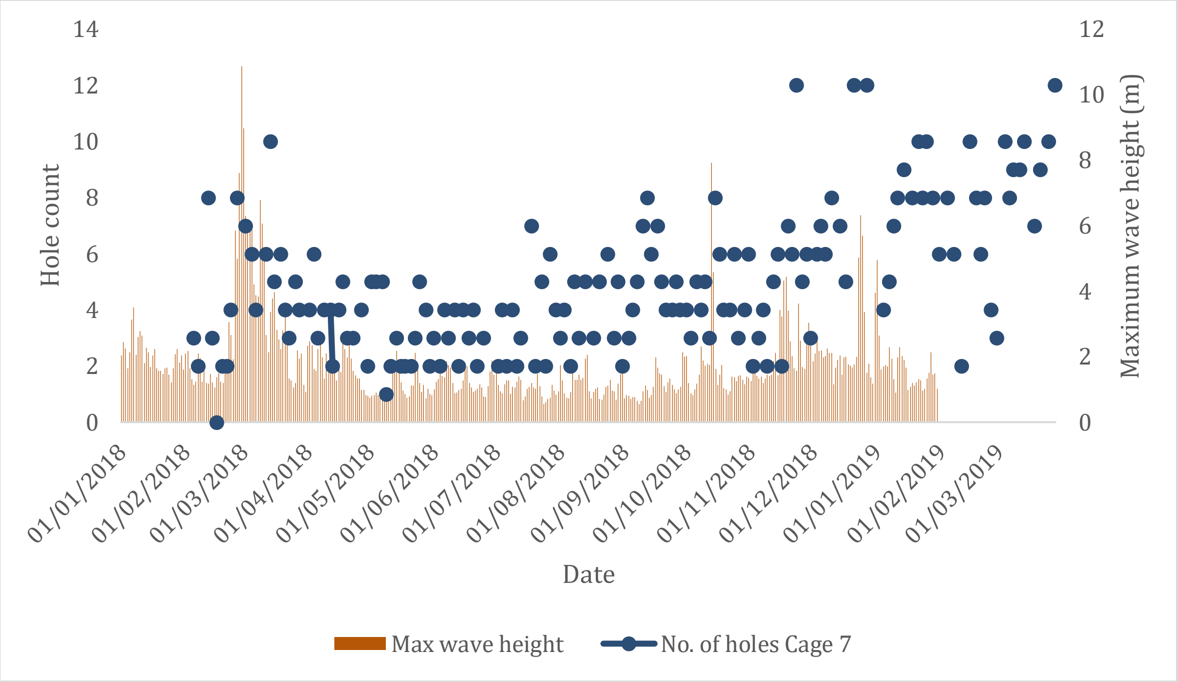


Figure 2.24 Scatterplot of the maximum wave height (m) plotted versus the number of holes counted at the fish farm in Calheta from January 2018 to March 2019 for cage 7

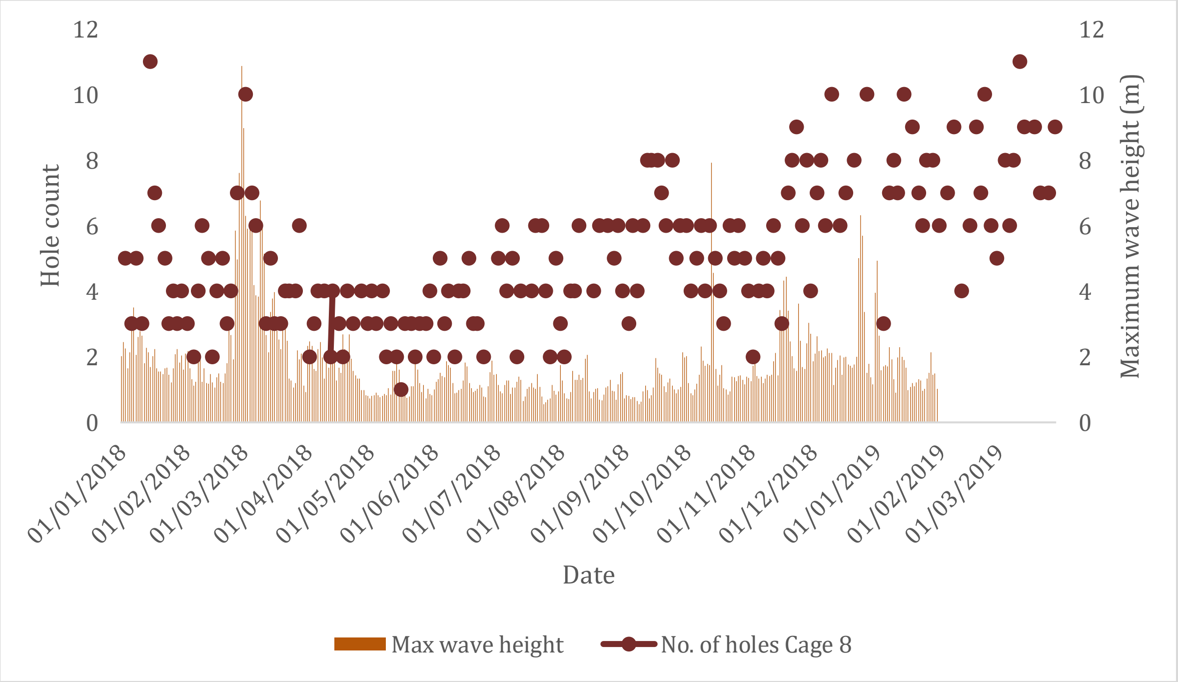


Figure 2.25 Scatterplot of the maximum wave height (m) plotted versus the number of holes counted at the fish farm in Calheta from January 2018 to March 2019 for cage 8

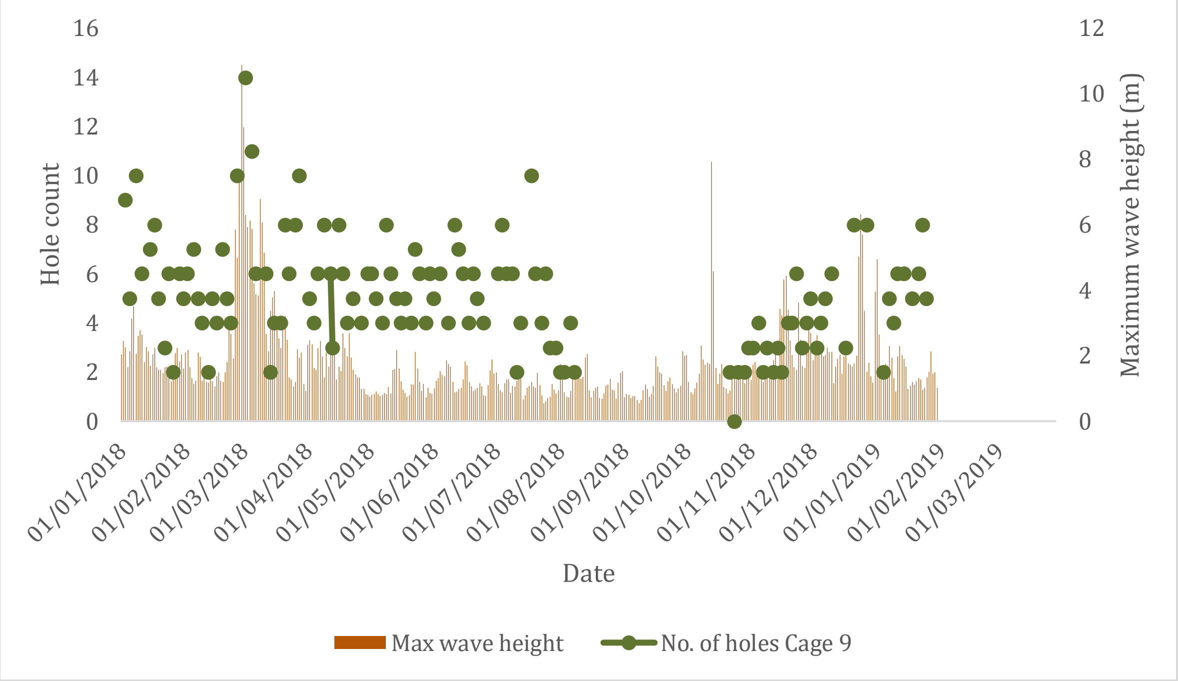


Figure 2.26 Scatterplot of the maximum wave height (m) plotted versus the number of holes counted at the fish farm in Calheta from January 2018 to March 2019 for cage 9

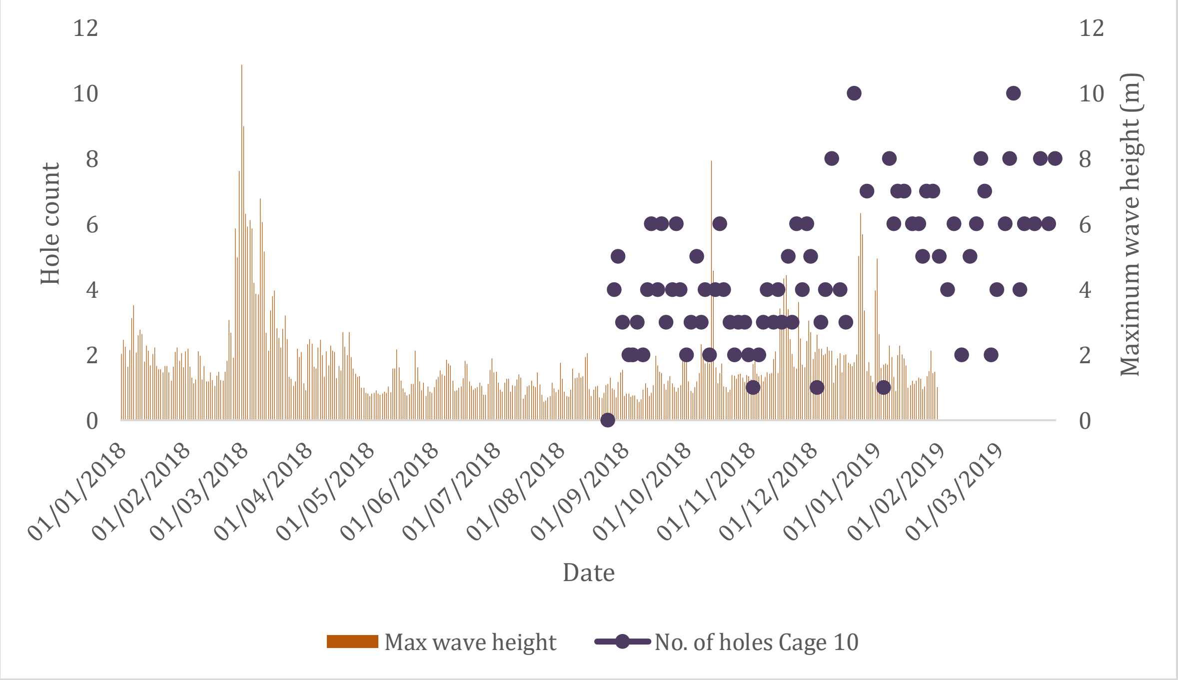


Figure 2.27 Scatterplot of the maximum wave height (m) plotted versus the number of holes counted at the fish farm in Calheta from January 2018 to March 2019 for cage 10

Appendix IV Table on Presence/Absence data of fish species recorded with an underwater camera system near the fish farming facility of Calheta, Madeira Portugal, 1= present, 0 = absent.

Date	***T. ovatus***	***S. maderensis***	***O. melanura***	***S.viridensis***	***T. picturatus***	***B. capriscus***
14/12/2018	1	1	1	0	1	0
08/01/2019	1	1	0	1	0	0
11/01/2019	1	1	1	1	0	0
15/01/2019	1	1	0	1	0	1
18/01/2019	1	1	0	1	0	0
24/01/2019	1	1	0	0	0	0
31/01/2019	1	1	0	0	0	0
07/02/2019	1	1	0	0	0	0
12/02/2019	1	1	0	0	0	0
19/02/2019	1	1	0	0	0	1
28/02/2019	1	1	0	0	0	0
07/03/2019	1	1	0	0	0	0
19/03/2019	1	1	0	0	0	0
21/03/2019	1	1	0	0	0	0
26/03/2019	1	1	0	0	0	0
28/03/2019	1	1	0	0	0	0
09/04/2019	1	1	0	0	0	1
18/04/2019	1	1	0	0	0	1
26/04/2019	1	1	0	0	0	0

Appendix V Fish farming facility of Calheta in rough sea conditions

Appendix VI Farm workers of the fish farming facility of Calheta during regular inspection/ reparation dives at the nets of the fish farm

Appendix VII Abstract for the AE2019, Berlin

THE REASONS BEHIND THE ESCAPES OF *S. AURATA* FROM MADEIRAN FISH FARMS-RISK ASSESSMENT THROUGH THE ANALYSIS OF ARCHIVE DATA

Johannes Müller*

Centro de Maricultura da Calheta Av. D. Manuel I, n. º7 9370-135 Calheta Madeira (Portugal)

Universidade do Algarve Faculdade de Ciências e Tecnologia (FCT) Campus de Gambelas, Edifício 2 8005-139 Faro (Portugal)

Email: Johannes.Mueller-Lindenberg@web.de

Introduction

Intensive fish farming has been a growing industry in recent years in the Mediterranean Sea and the North-East Atlantic; with the gilthead seabream being a commonly farmed species. Around Madeira, an archipelago situated in the North Atlantic, *Sparus aurata* was recorded in the wild shortly after farming of this species in offshore net-cages started in 1997. Escape-events from fish farms are most likely the reason for the introduction of *S.aurata* to the waters of Madeira, with a wide range of possible risks. Many factors are involved in escape events. Large scale escape incidents are related to the formation of holes in the net cage, which can be caused by rough sea conditions (e.g. storms), but also through predator attack and the net-biting activity of the farmed fish. Farm owners monitor the condition of the farming facilities and recorded damage are recorded in archive files.

Materials and Methods

Historical archive data from 2018 and 2019 collected from fish farms on Madeira Island in Calheta, Caniçal and Ribeira Brava (data from regular inspection dives around farming facilities and operational data) was evaluated with the inclusion of relevant factors, such as data on sea-conditions and data on the farming conditions provided by the farms.

Results

Detailed data analysis of present material has yet to be performed and results may provide information on the most relevant causes of escape events from Madeiran fish farms, including a massive escape event, that took place in 2018.

Acknowledgements

This study was performed with the help of Dr. Carlos Andrade at the Mariculture Centre in Calheta, Madeira (Portugal.)