



Norwegian University of
Science and Technology

Smart Release Pods for Juvenile Lobster in Sea Ranching

Adelaide Mellem

Master of Science in Cybernetics and Robotics

Submission date: June 2016

Supervisor: Jo Arve Alfredsen, ITK

Co-supervisor: Morten Alver, SINTEF

Norwegian University of Science and Technology
Department of Engineering Cybernetics



NTNU
Norwegian University of
Science and Technology

**Faculty of Information Technology,
Mathematics and Electrical Engineering
Department of Engineering Cybernetics**

MASTER THESIS

Name: Adelaide Marie Mellem
Program: Engineering Cybernetics
Thesis title: Smart release pods for juvenile lobster in sea ranching
Title (Norw.): Smart-utsetter for hummeryngel i havbeite

Project description

European lobster is regarded as a promising candidate species for sea ranching. Sea ranching involves stocking of hatchery-produced juveniles in the natural environment where they are allowed to grow freely and boost the harvestable population of the ranching site. Current interest in establishing lobster ranching sites along the Norwegian coast has stimulated innovation and the search for solutions and technology that can facilitate survival, growth and quality throughout the production chain. Transfer and settling of hatchery-grown juveniles in the sea ranching site is regarded as one of the critical operations that could potentially benefit significantly from technological innovation. Finding ways to enhance this operation will be the point of focus for this project. The project includes the following tasks:

- Survey of literature on lobster behaviour and identifying previous experiences and practices with sea ranching of this species
- Apply a fine-scale hydrodynamic model (SINMOD) with realistic wind fields and tides to simulate the spatio-temporal spreading patterns of lobster juveniles of stage IV-V released at a specific sea ranching site under varying assumptions concerning:
 - Lobster behaviour - from passive particles to active individuals (swimming, crawling, clenching)
 - Release sites and release strategies such as state-of-the-art passive release, swarm release and release with respect to tidal current phases
 - Predation risk
- Make an analysis of the resulting spreading patterns and suggest release strategies that facilitate favourable spreading and settling of lobster juveniles as well as reducing predation risk
- Use the analysis to work out a requirements specification for an active stocking device (smart release pod) capable of implementing suggested release strategies within practical and economic constraints
- Develop a smart release pod prototype, make tests, document and discuss its properties

Project start: 13/1 - 2016

Project due: 8/6 - 2016

Host institution: Department of Engineering Cybernetics (DEC), NTNU

Supervisor: Jo Arve Alfredsen, DEC, NTNU

Co-supervisor: Morten Omholt Alver, SINTEF Fisheries and Aquaculture/NTNU, DEC

Jo Arve Alfredsen
Trondheim, 13/1 - 2016

Abstract

Sea ranching of lobster is a sustainable alternative to mere fishing. The method involves releasing hatchery-reared juveniles into their natural environment, usually at a geographically delimited area. With this addition to the native populations one hopes to raise the overall numbers of specimens and increase the catching rates and financial gain.

Being small the juvenile lobsters are amongst the lower levels of the food chain. Predators are abundant all year round making the release process a dangerous affair. But the young lobsters size is not only a disadvantage when it comes to the food chain hierarchy; ocean dynamics such as currents may largely contribute to the dispersal, transporting the lobster miles away from the sea ranching site. These are amongst some challenges that if solved will increase the benefits of sea ranching. This thesis had the aim of addressing these problems and try to enhance the process focusing on release strategies.

A literature survey was conducted to gain knowledge on ecology and behaviour of the European lobster *Homarus gammarus* and to get familiar with the practise of sea ranching by reviewing previous experiences and improvement suggestions. Based on previous research several biological models of juvenile lobster behaviour were made. These were incorporated with the fine-scale hydrodynamic model SIN-MOD to look at spatio-temporal spreading patterns. The simulated releases were conducted at a specific site with environmental data from the period of May 1.-May 14. 2012. Simulation data were analyzed in terms of biological model used, time of day and flow fields. Results reveled that the lobsters vertical placement in the water column (depth) is most influential in terms of the amount of current induced transport. Because of the scarce amount of conclusive information on lobster behaviour, no immediate conclusion could be drawn. Some suggestions however were made based on the knowledge gathered. Releasing of older stage IV juveniles, or stage V juveniles is encouraged as more lobsters will settle at the sea ranching site. Releases should be conducted at night due to predators impaired vision in darkness.

Sammendrag

Bruk av hummer i havbeite er et bærekraftig alternativ til fangst alene. Havbeite går ut på å sette ut oppdrettsyngel i sitt naturlige miljø, sjøen, vanligvis i et geografisk avgrenset område hvor den ansvarlige har tillatelse og enerett på gjenfangst. Håpet med utsettingen er at den skal øke bestanden og dermed gi økonomisk gevinst i form av økt fangst.

Den utsatte hummeryngelen er liten og hører til blant de lavere nivåene av næringskjeden. Da rovfisk og skalldyr er å finne året rundt gjør disse utsettelseprosessen utfordrende. Men det er ikke bare risikoen av å bli noen sin middag som påvirkes av hummerens størrelse. Strømmen i havet er sterk for et dyr på noen titalls millimeter og kan i værste fall føre til at hummeren blir transportert ut av havbeiteområdet. Både tap av yngel til rovfisk og transport ut av området er uønsket av økonomiske årsaker. En løsning på disse utfordringene vil kunne øke fordelene ved havbeite. Denne oppgavens mål er å prøve å ta tak i noen av disse utfordringene.

En litteraturstudie ble utført for innhenting av informasjon og hummerens biologi og ekologi, samt nåverende tanker og praksiser knyttet til havbeite. Observasjoner fra tidligere forskning ble brukt til å modellere flere mulige oppførselsprofiler av hummer. Disse ble kombinert med den hydrodynamiske modellen SINMOD for å simulere spredning. Dataene fra simuleringen ble analysert for å se på forskjell i spredning og bunnslåing av hummeren, og for å se hvilke miljøfaktorer (tid, strømretning og fart) som påvirket resultatene. Et spesifikt område ble brukt i simuleringen, med data fra 1-14 mai 2012. Resultatene av analysen viste at den vertikale posisjonen, altså dybden, hadde mest å si på hvor stor transporten ut av området ville være. På grunn av få konkluderende studier å basere den biologiske modelleringen på var det ikke mulig å konkludere med noe håndfast utifra resultatene. Noen forbedringer ble foreslått basert på det som ble funnet. Disse går på å slippe ut hummer i stadium IV som er minst et par dager gamle, da disse naturlig er å finne nærmere bunnen. Gjærne burde stadium V hummer brukes. Utslipp bør foregå på bunnen og gjøres på natten for å minske risikoen for rovdyr.

Preface

Humans often find it necessary to meddle with the ecosystem to straighten the mistakes of past generations. Technological leaps, growing human populations, pollution and unsustainable catching rates have led to large changes in the numbers of several species. Many marine creatures too, are in deep water, having suffered from severe population disintegration. The lobster is one of the sea animals that has been forced upon this uncertain fate as many of the stocks can be described as collapsed. However a global trend has for a while been turning the spotlight over to sustainability, enhancement and environment. In another department, computing power in combination with mathematical modelling is reaching areas never considered or possible before. Using technologies that go beyond biology and classical field work, the world of aquaculture has found an ally in the control freak driven science of cybernetics.

Working with alcohol and EEG signals on my project thesis last semester, I shrilly could not go with the stream and choose something ordinary and expected this time either. Looking through the different theme suggestions, amongst the sea of common cybernetics terms like UAV, robot and drone, one immediately stood out: “juvenile lobster”. Diving into this project with curiosity I was shore that the work would be interesting and rewarding. But to be honest, sometimes I felt like a fish out of water, not being certain if I was to be finished in tide. Regardless working this semester has been a learning experience, and quite amusing at times, and I hope that what i have done is somewhat useful, and not just another drop in the ocean. What I have learned is that the science of cybernetics is like a potato, it goes with everything, even lobster.

This report presents the work done on the master thesis carried out spring 2016. Just like the author of this report it is assumed that reader has a technical background and is lacking a deeper understanding of the biology and ecology of the lobster, stock enhancement and the more specific details of the ocean’s dynamics.

Trondheim, 2016-06-06

Adelaide Marie Mellem

Acknowledgment

I would like to thank my supervisor Jo Arve Alfredsen for giving me the opportunity to work with this different yet interesting topic, and for always being helpful and contributing with good answers and help during my work.

My second supervisor Morten Alver deserves huge thanks for making the model available for me to use and for providing great help and carrying out the simulations.

I really appreciate the information and input received from Norsk Hummer, and for the numerous biologists I have bothered over email: thanks for being so helpful and eager to contribute!

Lastly a little thanks to the great composers Chopin and Yiruma for their calming music that has kept my concentration at decent levels, protecting me from the cacophony of the surrounding zoo-like environment that was my office.

A.M.M

Contents

Abstract	i
Sammendrag	iii
Preface	v
Acknowledgment	vii
1 Introduction	3
1.1 Background and motivation	3
1.2 Objective	5
1.3 Limitations	6
1.4 Structure of the report	6
1.5 Notes	7
2 A Dive into the World of the Lobster	9
2.1 Lobster life	9
2.2 Sea ranching	13
3 Model Description	17
3.1 Motivation	17
3.2 SINMOD description	18
4 Modelling Lobster Behaviour	21
4.1 Initial thoughts	21
4.2 Litterature research	22
4.3 Approach	24
5 Simulation Details	27
5.1 Biological model	27
5.2 Model parameters	29
5.3 Overview	32
6 Simulation Analysis	33

6.1	Practicalities	34
6.2	How results are presented	34
6.3	Initial trials	35
6.3.1	Settlement overview	35
6.3.2	Settlement numbers	36
6.3.3	Total time spent in sea ranching area	36
6.4	Increasing vertical migration with different speeds	37
6.4.1	Settlement overview	37
6.4.2	Total time spent in sea ranching area	38
6.5	Constant behaviour	38
6.5.1	Settlement overview	40
6.5.2	Total time spend in sea ranching area	40
6.6	Passive particles	43
6.7	Comparisons	43
6.7.1	Surface releases vs Bottom releases	43
6.7.2	Early settling and no early settling	44
6.7.3	Increasing vertical vs constant vertical	46
6.8	Dispersal beyond model grid	46
6.9	Current	47
6.10	Site and release time differences	49
7	Discussion	53
7.1	Simulations	53
7.1.1	Behaviour	53
7.1.2	Settlement and time spent in ranching site	54
7.1.3	Distribution patterns	55
7.1.4	Ocean Dynamics	55
7.1.5	Sites	55
7.1.6	Improvements and further work	56
7.2	Strategy improvement	57
7.2.1	Predation avoidance	57
7.2.2	Simulation results	58
8	Conclusion	59
8.1	Conclusion	59
A	Acronyms an Glossary	61
	Bibliography	62

Chapter 1

Introduction

At a first glance Lobster technology seems like having very little in common with the science of cybernetics, robotics and control. Today most associations to lobster fishing are still of old, tired fishermen, taking their boats out at dusk to gather whatever has gone into their traps during the night. This image however, is not that far from the truth as 200 years after its invention, the lobster trap is almost exclusively the only method used to catch lobsters today [1]. The lobster catching process has actually proven to be almost too effective, as many stocks now are considered to be at critically low levels. But there are other aspects of lobster fishing worth looking into with both financial growth and sustainability in mind, and that might be open for improvement and assistance from the world of cybernetics. This thesis aims to show just how.

1.1 Background and motivation

Accompanied by caviar, foie gras and oysters the lobsters has rested for decades on the top levels of the culinary world as an emblem of luxury, immortalized in the pop culture as a red symbol of wealth and fine dining. However being appealing to humans has historically not been a good trait for a species to possess and has caused more than one population to suffer towards extinction. The lobster is no exception; starting out as bountiful, overfishing led to high a demand and growing prices, further motivating an increase in fishing rates. Now many stocks, including the Scandinavian, are described as collapsed [2].

Over the years fishing regulations governed by law were introduced to help protect the stocks of (amongst other marine creatures) the lobster. The first lobster protective measures were taken in the early 1800 (in the USA), mainly focusing on prohibiting fishing for foreigners without permission. Subsequently more specific rules followed, such as introducing a minimum catching size or banning any catching of egg bearing females [1]. With varying degree the stocks started to repopulate. Today populations are still far from close to their initial levels, and many biologists agree that stronger measures need to be taken. Since prohibiting fishing in total, which seems to be the most effective strategy, is undesirable considering business, employment and the need to satisfy the market, an idea formed during the late 1800 involving the release of land-hatched lobsters into the wild.

The Norwegian cybernetics pioneer Jens G. Balchen was an eager contributor to the combination of cybernetics with the world of aquaculture and fisheries. Amongst various ideas and work with robotics and modelling in rearing and fishing facilities, he also speculated in lobster technology combined with automation, focusing on hatcheries. Successfully hatcheries were built, one of the largest in Kyrkjæsæterøra, Norway, and during and after the midst's of 1900 many lobsters were released i Norway, United kingdom, Ireland and USA [1].

Although lobster hatcheries now exist, and stock enhancement by releasing juveniles is a common procedure, little is known about the actual impact of these efforts. The somewhat complicated biology and unknown behavior patterns of young lobsters contribute to the uncertainty. The lobsters also grow slowly, making the process of drawing conclusion from any actions performed taking time accordingly. Over a growing period of roughly 5-8 years, environmental factors, such as predators, temperature, currents and fishing affect the distribution and survival rate of the released lobsters. Therefore most of the research is unable to conclude if the procedure is to be labeled successful.

But the motivation to develop methods for successful release of lobster juveniles goes beyond stock enhancement. In 2001 the Act on Sea Ranching [3] was approved in Norway, giving monopoly to catch a type of specimen in an area given that stock enhancement is practised. As of today *Norsk Hummer* is one company that practises sea ranching of lobsters in Norway, releasing juvenile lobsters during spring in a ranching site near the mid-west coast of Norway.

The method of sea ranching also suffers from the today unknown fate of the released juveniles. Apart from predators, Ocean currents could be the most crucial factor contributing to death and lobsters permanently leaving the sea ranching area. For population enhancement leaving the area and getting spread out in the ocean is

perhaps not a disadvantage, but for the financial gain (that comes from re-catching and is necessary to further invest in the process of stock enhancement) staying in the area is crucial.

Small adjustments to the releasing strategy, such as choosing the best time of day related to current and weather induced transport, as well as trying to minimize the presence of predators, might greatly reduce the number of lobster ending up as fish food or that are being carried away.

Biological field studies involving tags and re-catching are expensive and time consuming to do in large scales. As the computing power and knowledge of the dynamics of the ocean has increased, this has expanded the use of mathematical models. Ocean models are now used for several purposes, many for studying population dynamics, connectivity and dispersal of smaller marine animals. If these techniques can be applied with lobsters, and give useful answers, the future of lobsters and sea ranching might be brighter and more certain.

1.2 Objective

This thesis aims to see if one can combine mathematical models of the ocean with biological and ecological knowledge to gain information and hopefully improve the current strategies of stock enhancement and sea ranching processes.

The study will look at the time after lobsters have been hatched and are ready to start a new life at the bottom of the sea. Both the releasing process, including the stocking device, as well as the time after release will be analyzed.

Firstly the aim is to gain knowledge on the specimens of *Homarus gammarus* (European clawed lobster) focusing on behavioural traits. The information is later to be analyzed and combined to model a behaviour profile intended to be used in simulations. To inspect possible hydrodynamic transport and estimate ending locations for settlement, simulations using ocean models will be conducted. The aim is to look at dispersal not only due to sea dynamics but also the time of day and location. The information from the simulations will then be analyzed and discussed, and a release strategy proposed.

The geographical area of study will be connected to the Norwegian company *Norsk Hummer* that is currently applying stock enhancement at a sea ranching site in the mid-west coast of Norway. The focus is therefore mainly to further increase

the survival rate of their released lobsters and to see if the measures of their stock enhancement are to be considered beneficial. However the work will also partly aim towards more generally-applicable result.

1.3 Limitations

As far as the literature search has gone, there have not been many studies resembling the one presented here. Nor has there been a satisfying amount of conclusive studies about lobster behaviour in the post-larval and EBP stages. Thus the work will be based on qualifies guessing where no other option is available. The results should be applied with care accordingly, and perhaps be looked upon more as guidance and inspiration for further work rather than an actual conclusions ready to be put into practice.

Furthermore this research focuses on biological techniques that very much intend to (positively) meddle with the ecosystem and environment. Some ethical aspects arise and will be discussed, however briefly as the aim of this work is of technical improvement and practical analysis.

The work has been performed over a single semester, and proving to be time consuming, the focus shifted to simulation analysis and tuning of behaviours and parameters, leaving little time to concentrate on stocking device improvement.

1.4 Structure of the report

The rest of the report is structured as follows: Chapter 2 gives a theoretical overview of the necessities of knowledge on lobsters and stock enhancement. The model used in the simulations is described in chapter 3. Further chapter 4 takes a deeper look into the literature about lobster behaviour and includes a description of the process of defining the biological model. Chapter 5 presents all details of the simulations as well as explanations for the choices. In chapter 6 the results of the simulations are presented. Some approach to how they were obtained and comments are also included for increased readability. The final discussion is saved for chapter 7 where further improvements also are suggested. Chapter 8 sums up and concludes the work.

1.5 Notes

The lobster biologically covers numerous species. This report will use the term lobster meaning the clawed lobsters that is represented in two closely related species of the *Homarus* family, the American *Homarus americanus* and the European *Homarus gammarus*.

The term postlarva refers to a lobster of stage IV. The terms postlarva, stage IV lobsters and juvenile will be used interchangeably. The stages and life cycle will be more thoroughly explained in the next chapter.

If the reader encounters any unknown or previously unseen words or terms, please see to appendix A on page 61, as some needed explanations and acronyms are included there.

Chapter 2

A Dive into the World of the Lobster

Since this thesis mainly concerns the young lobsters, more specifically stage IV postlarvae, this section will focus on them alike. Some information about grown or older lobsters might be included when the author finds it necessary knowledge for the reader to be familiar with in order to better understand some parts of the following sections and results.

2.1 Lobster life

The lobster is born hatching from one of numerous eggs released by a mother lobster upon maturing. In the following period, the baby lobster lives as a shrimp-looking larvae, passively floating in the water, usually in the upper levels of the water column. Being a crustacean, which involves having an exoskeleton, the lobster grows by molting, a process described as shredding out of its old body when the skin becomes "too tight". In a period of 3-12 weeks, depending on temperature and food availability, the lobster goes through three such molts, from stage I to stage IV [4]. Upon molting into stage IV the lobster, now referred to as a postlarva, has reached it's final, characteristic shape, with claws pointing forward. Now it begins its quest to find a suitable shelter, where it can grow peacefully in many years without worrying too much about its numerous predators. It is believed that the lobster engages in bottom-seeking behaviour, diving towards the bottom with increasing frequency [5] [6].

Upon finding a suitable habitat the lobster takes its last dive towards the bottom. From now on it is a benthic creature that will spend most of its motion time by crawling at the bottom or digging tunnels in the sand [7]. It will however never lose its swimming ability, and will for all time be able to conduct fast tails flapping movement producing a swimming patterns consisting of backwards rapid bursts. If it survives the juvenile stages of growing, succeeding in keeping away from predators and other larger and stronger lobsters, it will continue to grow for up to seven years before reaching a size fit for the dinner tables.

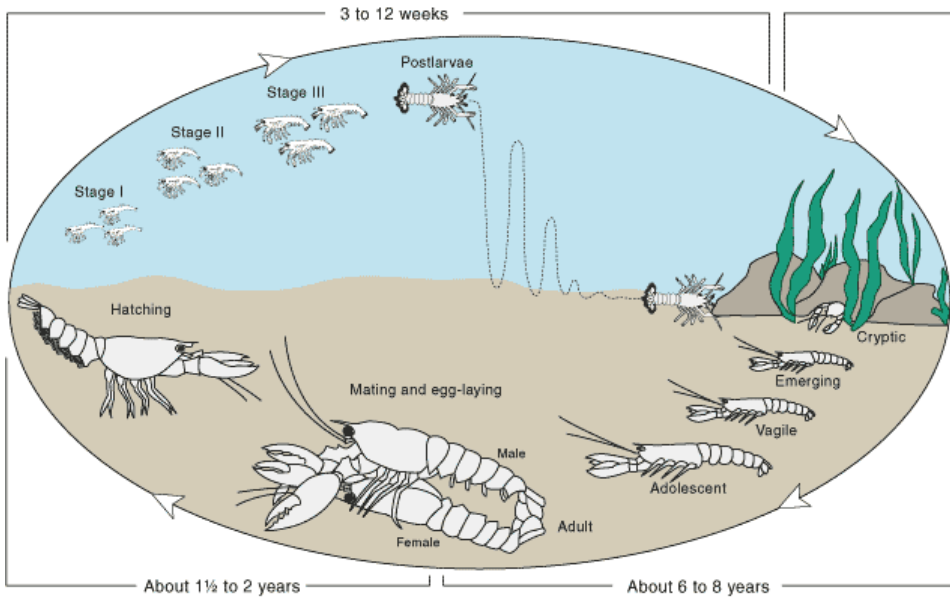


Figure 2.1: Lobster life cycle

Source: [8].

Americanus vs Gammarus

Research conducted on the European lobster *H.gammarus* are often based on, or referring to work done on the American lobster *H.americanus*. Geographically isolated in nature the two species are still closely related, both sharing the same four development stages as larvae [9]. Physiologically the European lobster tends to be somewhat longer and more narrow than its American cousin who in turn is heavier [10]. It suggests that the *H.gammarus* might be slightly more aggressive and prone to a higher mortality rate [9]. Other more specific behaviour differences are probably yet to be discovered, as not everything about the lobster, especially

concerning early life behaviour, has been fully mapped out.

Distribution and habitat

The *Homarus* family settlement covers large ranges of the more shallow parts of ocean waters. The habitat of the European lobster stretches from the northern sea of Scandinavian shores, as high up as the Lofoten isles, to the Mediterranean sea and coast of Morocco [11].

While the American juvenile lobster is known to favour cobbled substrata and rocks on sand [7], this information is not known about the European version. No specimens of early benthic phase (EBP) European lobster have been found on either sand, rock or cobble[12]. This suggest that, although similar in physiology and growth, some differences exist between these cross-Atlantic cousins, probably as a result of environmental factors like water temperatures and contrasts in predator abundance.

Early life

Little is known about the early life of young lobsters in the wild. Multiple studies have been conducted and knowledge gathered about the pelagic larval stages, but when the lobster molts to stage IV, and starts to look for a benthic habitat, it simply disappears from the radars of scientists for a good couple of years. Catching a juvenile lobster in the wild has proven to be a very seldom occurrence and in Norway no lobster of stage IV has been found in the wild by any type of studies conducted [12] [13]. Some smaller scale studies involving postlarvae observed by divers in the ocean short time after release, as well as laboratory studies have been performed. These will be discussed in the next chapter.

Lobsters are known to show dimorphism between claws. Being born with symmetrical claws (cutter), the transformation of one cutter-claw into a crusher claw occurs some time after moulting into the fourth or fifth stage [14]. Some hatchery reared specimens have shown a lack of development of the distinct crusher claw, proving that environment, and interaction with it, is important for the right growth.



Figure 2.2: *H.gammarus*, note the anatomical difference between left and right claw

Source: [15].

Predators

Larger fish such as cod, wrasses and sculpins, as well as other crustaceans like crab, are among the juvenile lobsters most common predators [16]. However, the lobster number one enemy, that it will never escape the claws and be fear-free of, no matter its size, is another lobster. Their highly cannibalistic nature makes them mortal enemies of each other as the best food a lobster knows is another lobster.

The life and abundance of certain species in the ocean changes with season. Common predators during the winter are never as abundant as predators during the summer [16]. These winter predators also usually prefer sandy substrates. A study done by the Institute of Marine research on predation after release, van der Meeren [16], suggest that best results occur if the juveniles are released on rocky substrate during winter. This study also emphasize the need to acclimatize the lobsters to the new environment and temperature to avoid panic like behaviour and confusion caused paralysis, which only benefits the predator.

When spring dawns upon the marine environment, in Norway being around March to April, many larger fish are busy mating and spawning, reducing their behaviour towards acquiring food. This season therefore makes for a good period for lobster survival and thus is the recommended time for releasing hatchery reared specimens. However, as it is still winter on land, with weather at sea tending to be inconvenient,

the releasing process is usually postponed to May.

2.2 Sea ranching

Sea ranching is a culture method involving the release of (usually) hatchery reared juveniles into a natural environment. The environment provides everything the animals need to grow, and has no need for any structure for regulation or containment [17]. The ones responsible for rearing and releasing the juveniles have the right to harvest the adult specimens exclusively. At least the latter is the practise in Norway after the Sea ranching act of 2001 [3].

Practise

Upon reaching stage IV, the lobsters are placed in some transportation devise and moved to the release site. Norsk Hummer uses cubical containers where the walls are three dimensional hexagonal cells that make small shelters with just enough room for one postlarva. The juveniles hiding behaviour makes them seek to hide in the tiny spaces, thus they are kept separated and aggression and fighting between specimens is minimized. The cases are lowered into the water and opened at the bottom, allowing the lobster postlarvae to swim out.

The transportation process has proven to influence the behaviour of the juveniles [18]. Previous strategies have included transportation in wet newspapers and releasing at the top of the ocean. However the dive towards the bottom is long, and exposed to predators, thus today's common practise is to release at bottom. In hatcheries, the larvae are exposed to high temperatures to boost development. If released into the ocean without acclimatisation to the low temperature, lobster have shown panic-like behaviour including immobility and rapid swimming upwards (pelagic rush). This can be an reaction to both temperature and pressure as argued by van der Meeren [18]. Clearly this sort of behaviour increases the lobsters mortality rate, as motion attracts predator and immobility makes the specimens easy targets.

Ethical concerns

Initially looking like a good idea, incorporating sustainability and enhancement, sea ranching might have some limitations and drawbacks:

Firstly, as mentioned in the beginning of this thesis, not all consequences of re-leasing juveniles into the wild are fully outlined. Although some studies has found tagged specimens years after release, no reliable survival rates are available. Thus the process might as well be a waste of time and money, as it is currently being practised.

In addition laboratory-reared lobsters have in the past had reported deficiencies, such as not developing crusher claws, Govind and Pearce [14] and Agnalt et al. [19]. This suggests that the hatchery environment lacks something crucial for the right development. One might hypothesize that the aggressive nature in combination with environmental factors that allow letting out on the aggression are strongly required for proper claw development. Studies such as Rooney and Cobb [20] found laboratory reared postlarvae to swim significantly slower than the ones captured in the wild. The lack of predators in their growing surrounding might cause the juveniles not to learn about danger and danger avoidance. Some differences in wild and reared specimens might not even be visible and yet to be discovered, as they might only emerge when the wild environment is encountered. A study focusing on naive lobster interaction and behaviour to environmental factors such as predators concluded that reared lobster have some sort of inherited response, but that both social experience and inherited responses are crucial to make a lobster well adaptable [21].

Further possible changes in the artificially reared, and later released, lobsters might lead to certain negative scenarios¹:

- The reared postlarvae might simply not be sufficiently adapted to ocean life and therefore be prone to higher mortality rates.
- Postlarvae that normally would not survive the development of the first stages in the wild environment, do so because of the highly suitable conditions, and by that bring worse genes into the gene pool when released, overall weakening the population.

Being researched to some degree, scientist for now agree that hatchery reared lob-

¹Other scenarios might also exist. These are the ones considered most important by the author.

sters are fit for the ocean. [21] and [22]

Chapter 3

Model Description

Influenced by weather and winds, tides, currents, the in and out flow of fresh water, salinity, pressure and mineral contents, modelling the ocean dynamics makes for quite a staggering task. Fortunately the large usefulness of these tools has driven the development to a point where several high resolution models exist. This section will present the model later to be used for the simulations.

3.1 Motivation

When concerning biology and population mechanics, ocean models can answer questions and reinforce hypotheses of genetic distribution due to current transportation or predict the spreading of diseases. In the ocean, most species live their early life as small pelagic creatures, many helpless against the force of currents, tides and winds. Thus, these small particles that are larvae, eggs or even smaller planktonic creatures can be transported over large distances, eventually populating areas miles from where they originated. For example, the salmon lice, now being a large problem for the salmon industry, might be released into the sea from any rearing facility and cause troubles to salmons large distances away. It is interesting and informative (and might even be preventive) to see where the current might carry them, and ocean models are perfect for this purpose.

Similarly for this thesis, we want to know if the released small postlarva lobster stay at the sea ranching site, or if they get spread out on to the open seas. The

latter case would not giving the desired growth in population for the sea ranching owners and their investors. Using a model like this might also answer questions concerning releasing strategies. For instance it might answer if the transport could be controlled in some way, for example by releasing the lobsters at a specific time.

Particle tracking models have successfully been applied in several research studies: Pedersen et al. [23], Pedersen et al. [24], Incze and Naimie [25]. Three components are required for proper functioning. Mainly a hydrodynamic model supplying the flow field is needed. The second component is a biological model describing parameters such as growth and behaviour of particles. Last a advection scheme is necessary to model the transport mechanism of the particles due to the flow fields.

3.2 SINMOD description

The numerical model used for the simulations is called SINMOD. This is a nested 3D model system coupling physical and biological processes in the ocean. The term *nested* means that larger scale models create boundary conditions that are used in smaller domain models with higher resolution. These again create boundary conditions for even smaller, higher resolution models. Along the coast of Norway 160 m resolution models now exist. [26]

SINMOD is leveled, which means it consist of fixed but permeable layers i the z (depth) direction. Each layer except the upper (at the surface) and the lowest (at the bottom) are of fixed size (because of level variations due to tidal activity, and bottom topography).

The details of the model setup can be found in table 3.1.

Horizontal resolution	160m
Vertical resolution (surface to bottom)	3m, 7×1m, 2m, 3m, 5 × 5m, 10m, 11× 25m, 11× 50m
Number of grid points (xy)	325 × 405
Time step	10 seconds
Samples stored every	30 minutes

Table 3.1: SINMOD setup parameters

The model is defined by the equations 3.1-3.4 (from Pedersen et al. [23]):

Momentum equation:

$$\frac{\partial \vec{u}}{\partial t} + \vec{u} \cdot \nabla \vec{u} + w \frac{\partial \vec{u}}{\partial z} + f \vec{k} \times \vec{u} - \frac{1}{\rho_0} \nabla p + A_H \nabla^2 \vec{u} = \frac{\partial}{\partial z} \left(v \frac{\partial \vec{u}}{\partial z} \right) \quad (3.1)$$

Continuity equation:

$$\nabla \cdot \vec{u} + \frac{\partial w}{\partial z} = 0 \quad (3.2)$$

Hydrostatic equation:

$$\frac{\partial p}{\partial z} = -\rho g \quad (3.3)$$

Salinity and temperature equation:

$$\frac{\partial \varphi}{\partial t} + \vec{u} \cdot \nabla \varphi + w \frac{\partial \varphi}{\partial z} + K_H \nabla^2 \varphi = \frac{\partial}{\partial z} \left(v \frac{\partial \varphi}{\partial z} \right) + \delta \varphi \quad (3.4)$$

Particle Tracking model (Pedersen et al. [24]):

$$H(\mathbf{R}, \underline{v}; p) = \frac{v_1/R_1^p v_2/R_2^p v_3/R_3^p v_4/R_4^p}{1/R_1^p 1/R_2^p 1/R_3^p 1/R_4^p} \quad (3.5)$$

The flow field is interpolated separately in the horizontal and vertical dimensions.

The state variables and parameters are as follows(Pedersen et al. [24]):

- \vec{u} - horizontal velocity vector
- w - vertical velocity
- A_h - horizontal eddy diffusion
- K_h - horizontal eddy diffusivity
- φ - state variable (temperature or salinity)
- f - coriolis parameter
- p - pressure
- ρ - density
- v - vertical eddy viscosity and diffusivity

- δ_φ - heat exchange between sea surface and the atmosphere

Chapter 4

Modelling Lobster Behaviour

Not long after starting the search for information on lobster behaviour it was clear that this would be a difficult task. Few conclusive studies had been conducted and those who did have some results to present were usually restricted to laboratory and tank environments, which are hard to compare with the ocean. Many theories on lobster behaviour turned out to be from diver observations and anecdotes. For this reason this work ended up being much of tuning and trying different things to find out what matters and what does not. The aim primary to find a realistic model, but also to look at worst case scenarios. Thoughts and ideas emerged all through the working period. For example, as pointed out by Norsk hummer towards the end, older lobsters tend to stay more at the bottom after release, could it be profitable to release older stage IV lobster when considering transport out of area? What would be the difference of a young postlarva and an old, and how could this be represented in the model?

4.1 Initial thoughts

Before starting simulations, various aspects and details had to be determined. In order to establish the biological facts, such as behaviour, growth period and predation numerous sources had to be researched and evaluated. This section will present, explain and discuss these specifications.

Prior knowledge, intuition and information gathered along the way, as well as some trial and error has strongly guided the choices of parameters for simulation and

analysis of this work. For this reason a short discussion is presented in the following paragraphs to line out the thinking process and perhaps clarify some of the choices that were made and that are described later in this chapter:

Firstly lobster larvae are small, but not *that* small. Hence initial assumptions were that the ocean mechanics would significantly influence the transport, however not exclusively, as the lobster are able to swim against some currents. Furthermore, tidal activity was suspected of being the most influenceable variable. Mainly because appearing twice a day, it is the most permanent yet changing environmental factor.

Since little information was available, and not conclusive enough to be directly applied without care, the work turned towards trying different variables in the behaviour domain. It was looked upon as an interesting result to see if it would matter if the lobster swam or were passive. Similarly information about how different speeds contribute to the end result and how locations and/or depth affects the spreading of lobsters were all considered useful knowledge to obtain, mostly to gain more insight to the credibility of the work presented here.

4.2 Literature research

What is known and tediously documented about the lobsters nature is that they change their habitat from pelagic to benthic sometime after molting to the fourth stage. The exact details of how this happens are however not known. Research has been conducted to reveal swimming action and stage IV lobsters reaction to different substrates, temperatures and other environmental conditions, such as light. The aim of this review is to find material worth using as a base for simulation specifications and strategy enhancement.

Mobility

Stage IV postlarvae are quite functional swimmers, capable of rapid, directional swimming [20]. One study found that wild *H. americanus* postlarvae can accommodate swimming speeds of about 13 cm/s, Rooney and Cobb [20]. Further, the same study suggest that higher temperatures lead to increased swimming behaviour but found no evidence for difference in total time spent swimming during day or night in lower temperatures. The observations were done in a tank and with relatively

high temperatures (15-21 degrees Celsius). European waters tend to be colder and it is possible that the swimming speeds and time spent swimming are consequently lower. Activity of larvae also decreased with water velocity. Another study found that average swimming speeds (of *H. americanus*) were 18 cm/s observed in the wild, 13 cm/s for wild juveniles in the laboratory and 10 cm/s for reared juveniles [27].

Bottom seeking and settling

The *bottom seeking behaviour* involving short dives towards the bottom is described and observed in amongst other, Annis [5] and Lillis and Snelgrove [6]. It is postulated to be transition phase behaviour, from swimming to bottom dwelling, the hypothesis being that the lobster is "testing" the bottom to find suitable habitat. Annis [5] describes a sounding behaviour observed by divers releasing postlarvae in ocean waters. Postlarvae released near bottom, as well as older postlarvae remained near bottom when released there, while young and those released at top preferred the upper levels of the water column. This study does not suffer from the artificial conditions that arise in a lab, but the presence of divers might influence the behaviour of the postlarvae. Although the study argues that escape behaviour was rarely exhibited, the divers influence cannot be entirely ruled out. The study further proposes that larvae avoid the lowest temperatures, rarely descending into waters below 12 degrees.

It is not known when during the stage the postlarva settles. Some might settle early on, others at the end of stage four, with a smaller part even postponing settlement after molting to stage V [7].

Phototaxis

It is known that grown lobsters are influenced by light. Being nocturnal animals, their activity levels are highest after dusk [4]. The activity levels at night increase with the age of the lobster, starting in the later juvenile stages [28]. It is suggested that the behavioural patterns of larvae also are affected by light, however in the opposite way. Larvae during the first three stages are, as mentioned earlier, pelagic, and thought to have a positively phototactic response (attraction towards light). When and how the change from positive to negative phototaxis happens during the fourth stage is not fully understood. It was hypothesized that lobster postlarvae might be more active during the night, or merge lower into the water column at day.

However several studies conducted in laboratorial environments found incremental or no changes in behaviour due to different light conditions [29] [30]. der Meeren [21] found no significant difference in reaction to predators or fighting activity due to light intensity.

Habitat selection

Grown lobsters are known to seek shelters during the day. These consist of natural caves and burrows formed by rock and ocean bottom structures. The time before this, during the early benthic phase, is somewhat of a mystery. Theories have been presented, one of them involving the lobster engaging in burrowing behavior, digging tunnels in the bottom substrate that work as shelter. [7]. There is probably a difference between *gammarus* and *americanus* habitat preference [9] as *americanus* postlarvae and older juveniles are actually found in the wild contrary to the European version [12].

However, since a lot research remain to be done on the matter of habitat selection and *H. gammarus* distribution, this has not been accounted for in the biological models.

4.3 Approach

It was proposed from the start of the work to include a passive behaviour, i.e none behaviour by the particles in the simulation. The reasoning behind this thought was to gain a comparable possibly "worst case scenario", as it was hypothesized that this would cause the most extensive transportation of lobsters.

For horizontal movement, based on the lack of of information on the matter, it was decided to apply a behaviour with equal probability of moving in each direction (random). Trial simulations showed that this had no overall impact, and was thus left out of the model.

The vertical behaviour was chosen to apply downwards (towards bottom), with an increasing length where the maximum move distance is determined by speed. The distance increases with the age of the lobster. This was the most easy and agreeable interpretation with reference to previously described thoughts and observations from earlier research of stage IV lobsters searching for the bottom. It is also agreeable with the earlier mentioned thoughts and observations of older stage IV

lobsters keeping more to the bottom layers.

Initially four variations of behaviour were simulated. The first was the worst case passive particle profile. The next three would have the described vertical bias downwards with different speeds, and the last profile would also include the possibility of early settling.

Looking through the results of this analysis drove the work further to try the last of the described behaviours with different speeds, and to include two more settling locations. This last behaviour seemed like the most realistic one, but with too large speed. Further early settling was removed from the behaviour specification, as one wanted to look at total time spent in the sea ranching area.

Later constant vertical behaviour was chosen, as well as a profile where the lobster would have a constant position near the bottom to representing a older stage IV lobster. The reason behind this was to investigate the speculation that older lobster tend to stay closer to the bottom.

Chapter 5

Simulation Details

Practical elements such as time of year, location within sea ranching area and release numbers had to be decided with practicality and credibility in mind. This chapter presents all details and aspects of the simulations, both of the biological models and practical details. Reasons for choices are also included.

5.1 Biological model

The work from 4 is further described and specified here. Other biological details used in the simulations will also be specified.

The different lobster behaviour profiles are as follows:

- Particle, no behaviour, all movement is due to passive drifting (**PP**)
- Vertical movement with increasing distance downwards (**VI**)
- Vertical movement with increasing distance downwards, and the possibility of early settling (**VI+ES**)
- Vertical movement with constant bias downwards (**VC**)
- Constant distance over bottom (**PC**)

Stage duration/Degree days

Growth of marine creatures is often represented in degree days. Higher temperatures often result in higher enzymatic reaction rates [31], causing the development time, especially in the larval stages, to be temperature dependent. Degree day is a measurement of temperature-over-time requirements for growth into the new stage. No publications of *H.gammarus* degree days were found, thus an estimation was used. In rearing conditions with water temperatures of about 18-20 degrees, stage IV to V durations are observed to be 3-5 days with food being plentiful. This accounts for about $19 \cdot 476$ degree days (using the means).

Settling

The simulations include early settling as well as no settling. Lobsters in stage V are usually bottom dwelling. Presumably, the settling occurs sometime close to the molt, when suitable habitat has been found [7]. Since the details are not known, simulations will assume the following:

1. When the lobster has accumulated enough degree days, it molts to stage V. This is represented in the simulation as an instant drop to the bottom by the lobster particle upon reaching the right amount of degree days. The lobster then does not move into the water column, as it is assumed to be bottom dwelling from now on.
2. In some simulations the possibility of early settlement will be used. This has a chance of occurring when the lobster is close to the bottom. This probability of a lobster to settle early increases with time. The maximum early settling probability is 10% per hour.

Vertical movement

Particles represented with this behaviour have the possibility of vertical movement with a maximum distance determined by different speeds and the time spent in the fourth stage. The distance is either increasing based on development stage (calculated by degree days accumulated) or constant (determined only by the speed used).

Speed

Because of the limitation of the speed measuring studies presented earlier in this section, particularly concerning temperature differences between the ocean and laboratory tanks, as well as lobster size differences, the results are only used as a guidance. To see what impact speed has on the transportation different numbers were chosen. All based on observations and studies mentioned in section 4.2 in chapter 4. Speeds used in the simulations are: $0.05 \frac{m}{s}$ and $0.10 \frac{m}{s}$ and $0.20 \frac{m}{s}$.

5.2 Model parameters

When deciding the more practical specifications such as release locations, time and period, several choices existed. In this section they are presented and explained.

Location

The simulated releases were conducted at the sea ranching site used by Norsk Hummer, at three different stations, depicted in figure 5.1 and further described in table 5.1. The sites were chosen to be a selection covering different parts of the ranching site, all with different depths. Most simulations included particles to be released 1m over ocean floor. Some simulations were done with surface releases for comparison (1m below sea level).

Table 5.1: Release site depth distribution

Site	Depth [m]
1	6
2	11
3	15

Time

Lobster are released over a period of 24 hours, at two hour intervals, from 1st of may at 00:00. The simulation period stretches from 1-14 may, the weather and current data being gathered from 1st of may to 14th of May from the year 2012. May is a natural choice as spring is a practical period regarding weather and temperatures

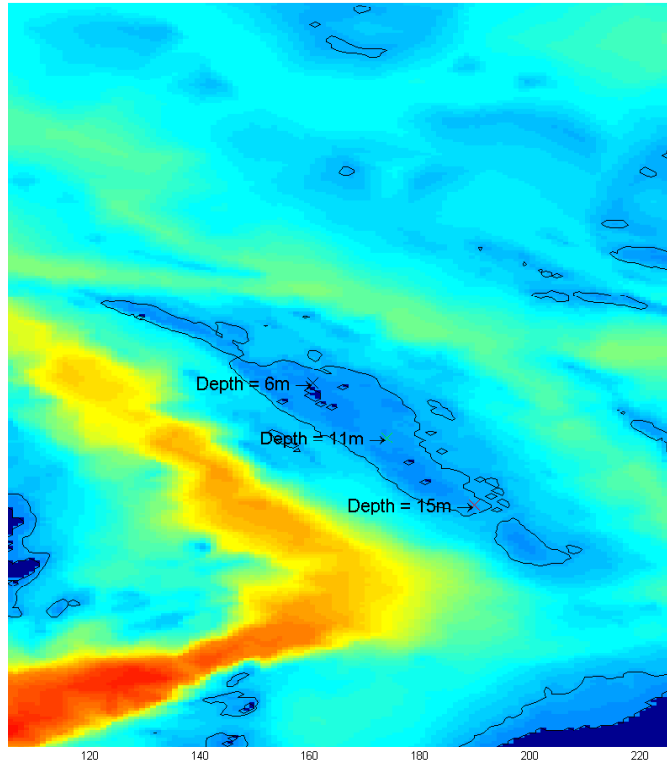


Figure 5.1: Sea ranching area with release sites rendering and contouring is included to illustrate depth.

and therefore a commonly used time to release reared lobsters. Stretching the releases over a 24 hour period ensures that possible effects due to tidal activity are included. 14 days sufficient time for particles to molt to stage V.

Data acquisition

The model runs with a time-step of 10 seconds. Current data is recorded every 10 minutes while simulation data, such as coordinates of particles, is recorded every 30 minutes.

Amount at release

The amount of lobster released at each time is 500. Currently the practice by Norsk Hummer is to stock about 200 lobsters per release pod, although the pod's carrying capacity is roughly 2-3 thousand.

Limitations

Apart from the obvious and already mentioned fact of the "educated guessing", as well as the inadequacy of essential knowledge on behaviour, some other points have to be mentioned:

- Some studies suggest that lobsters are able to postpone the molting process when no suitable habitat has been found [7]. This has not been accounted for.
- The degree day calculations is by no means scientifically suitable. However it is based on observations and experience, and count for a qualified guess and the best option as no other information on this is available.
- Horizontal movement has not been incorporated as a result of initial simulation trials revealing that this has no impact on the resulting transport. A study resembling the work done in this thesis has used a horizontal movement towards magnetic North [32]. It is however not explained why.
- Some researchers have estimated that as many as between 10 and 20 % of released juvenile lobsters are killed during the first minutes of release [18]. Although predators are a high factor contributing to lobster death and therefore determining success or failure of stock enhancement, it was chosen not to be incorporated in the simulations. A more detailed discussion on the predation avoidance together with suggested solutions will be conducted in a later chapter.
- Some research hypothesize that lobsters might use thermoclines to their advantage in order to avoid currents [16]. The model used in this work is not of a high enough resolution to make this possible to be accounted for.

Table 5.2: Simulation Overview

Site	Speed [m/s]	Released	Early settling	Behavior	Distance over bottom [m]
1	-	Top	No	Passive	-
1	0.20	Top	No	Increasing Vertical	-
1	0.10	Top	No	Increasing Vertical	-
1	0.20	Top	Yes	IncreasingVertical	-
1	-	Bottom	No	Passive	-
2	-	Bottom	No	Passive	-
3	-	Bottom	No	Passive	-
1	0.20	Bottom	No	IncreasingVertical	-
1	0.10	Bottom	No	IncreasingVertical	-
1	0.05	Bottom	No	Increasing Vertical	-
2	0.10	Bottom	No	Increasing Vertical	-
2	0.05	Bottom	No	Increasing Vertical	-
3	0.10	Bottom	No	Increasing Vertical	-
3	0.05	Bottom	No	Increasing Vertical	-
1	0.20	Bottom	Yes	IncreasingVertical	-
1	0.10	Bottom	Yes	IncreasingVertical	-
1	0.05	Bottom	Yes	IncreasingVertical	-
2	0.10	Bottom	Yes	IncreasingVertical	-
2	0.05	Bottom	Yes	IncreasingVertical	-
3	0.10	Bottom	Yes	IncreasingVertical	-
3	0.05	Bottom	Yes	Increasing Vertical	-
1	0.10	Bottom	No	Constant Vertical	-
1	0.05	Bottom	No	Constant Vertical	-
1	-	Bottom	No	Constant Position	1.0
1	-	Bottom	No	Constant Position	0.5
2	0.10	Bottom	No	Constant Vertical	-
2	0.05	Bottom	No	Constant Vertical	-
2	-	Bottom	No	Constant Position	1.0
2	-	Bottom	No	Constant Position	0.5
3	0.10	Bottom	No	Constant Vertical	-
3	0.05	Bottom	No	Constant Vertical	-
3	-	Bottom	No	Constant Position	1.0
3	-	Bottom	No	Constant Position	0.5

5.3 Overview

Table 5.2 shows an overview over all particle types used in the simulations.

Chapter 6

Simulation Analysis

In this section the main findings of the simulation analysis are presented and explained. In addition the author has chosen to include some approach and comments to the results as it is found to increase readability and comprehensibility. A more detailed overall discussion can be found in chapter 7. Only the most informative and interesting plots are included in this section.

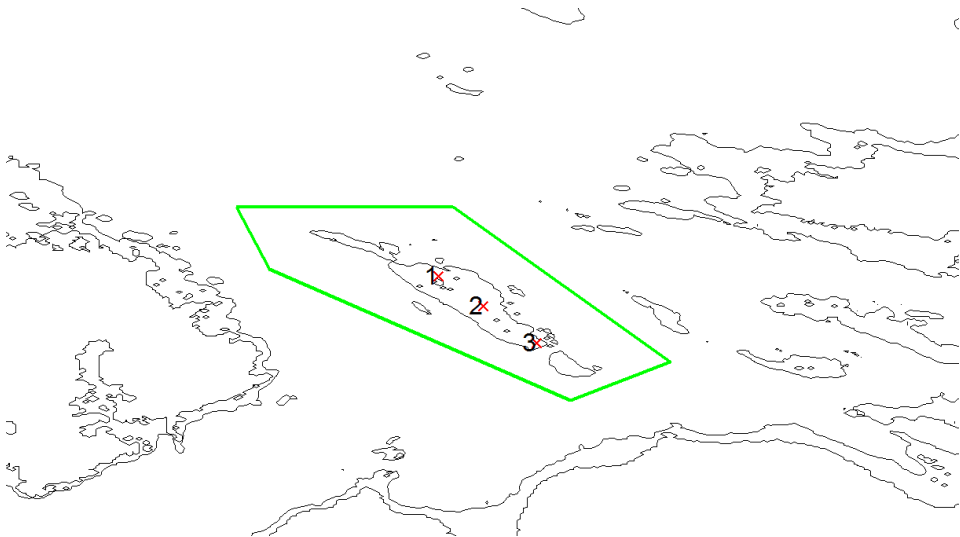


Figure 6.1: Area of desired settlement with release sites marked

6.1 Practicalities

A polygon area roughly covering the whole sea ranching site was defined to be used in the analysis. This polygon is depicted in figure 6.1. This area will be referred to as the polygon throughout this section.

In the simulations lobsters are represented as particles with different behaviours, therefore when using the term particle the author is referring to one instance of a lobster and not the passive-drifter particle behaviour profile (unless otherwise specified).

The analysis was conducted using matlab-scripts, and built in functions and analyzing tools provided by SINMOD.

6.2 How results are presented

The first sections in this chapter present the results of simulations with different behaviour profiles. They will include some or all of the following analyse methods:

Settlement overview

Initially simulation data was investigated by viewing plots and animations, focusing on the end position of the particles. Every plot shows the end positions of particles released at one release site (specified in the plot description). Lobsters are presented as black dots and the background is colored by depth, see figure 6.2.

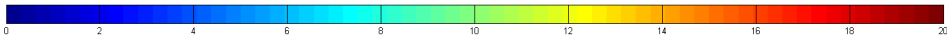


Figure 6.2: Color to depth. [m]

Settlement numbers

Some plots presents the results of further inspecting the amount of particles that ended up settling in the polygon area. These show the percent of particles settled at the sea ranching site.

Table 6.1: Simulation 1 details

Name	Behavior	Max speed	Site
Type1	PP	-	1
Type2	VI	0.10	1
Type3	VI	0.20	1
Type4	VI + ES	0.20	1

Time spent in sea ranching area

To get more informative and reliable answers it was decided to look at the total time spent in the polygon. Particles might move in and out of the area, but longer time spent in the polygon increases chances of settling which makes it a good measure of dispersal.

To get the time estimate, the position of each particle is checked at each sample (every 30 minutes) from the time of release. If the particle is inside the polygon borders, the time step is added to the total time. The simulations length is 13 days or 312 hours.

Some plots show the time spent in polygon in hours. When examining plots, remember that the total time of simulation (when all particles are settled) is 312 hours.

6.3 Initial trials

The four behaviours used in the first simulation are described in table 6.1. It was decided to try profiles with different vertical migration patterns to get an initial look of how they would differ. Only site 1 was used.

6.3.1 Settlement overview

The end positions of all particles are shown in figure 6.3.

It can be seen from the plot (figure 6.3) that close to no particles of type 1 (passive) stay in the polygon, most leaving the model grid area. The seemingly increase of black dots in the polygon with increased speed (from type 2 to type 3) suggest that speed and vertical behaviour has an influence on the total transport, deeper vertical

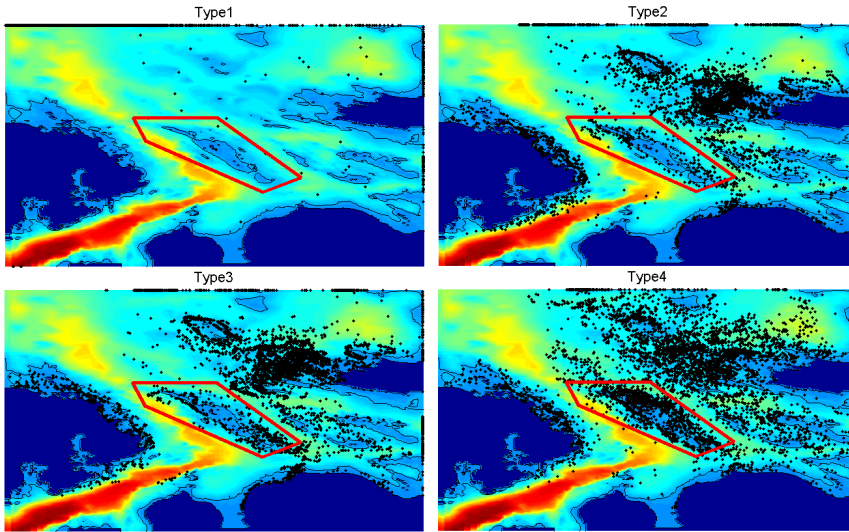


Figure 6.3: End position, four behaviours
See table 6.1

placement resulting in less current induced transport. Type 4, which includes early settling, clearly has the most particles staying in the desired area.

6.3.2 Settlement numbers

Figure 6.4 presents how much the different behaviour profiles influence the number of particles that ended up settling in the polygon. Particles are colored after type and grouped after release. The largest difference, between type 3 and type 4 is expected, as it is natural to assume that early settling will result in more particles in settled in area. Passive particles from all releases seem to drift out of the sea ranching site.

6.3.3 Total time spent in sea ranching area

Simulations were analyzed with respect to total time spent in polygon. Figure 6.5 show the result given in average time spent in area for all released particles.

Again type 4 show the most promising result, having the largest part of the simulation-time spent in the polygon. Type 1 particles, which are passive drifters,

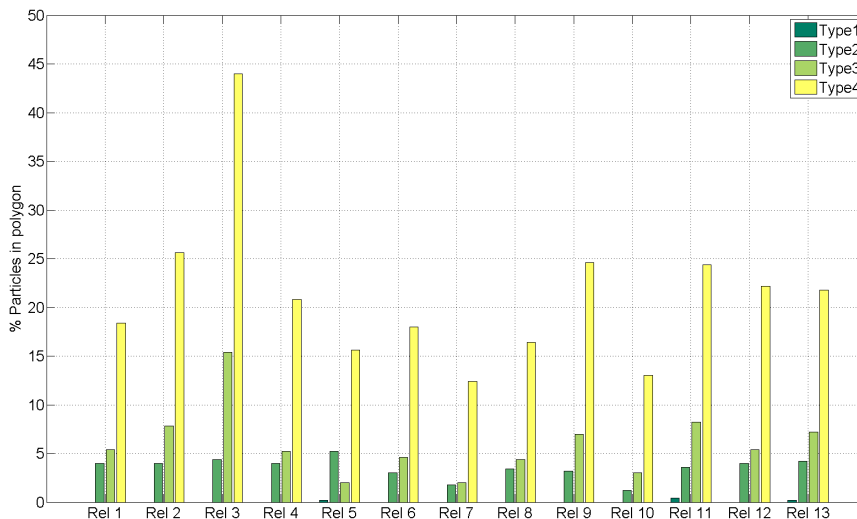


Figure 6.4: Percentage of settled particles
See table 6.1

spend on average 20 hours in the sea ranching site.

6.4 Increasing vertical migration with different speeds

Seeming like the most realistic behaviour. Types 3 and 4 from table 6.1 (increasing vertical behaviour with and without early settling) were chosen for further inspection. Different (smaller) speeds were chosen as well as two additional release sites. Simulations both with and without early settling were conducted, however this section includes only analyse of the trials without early settling. An overview of the types is given in table 6.2).

6.4.1 Settlement overview

Table 6.2: Simulation 2 details

Name	Behavior	Max speed	Site
Type1	VI	0.05	1,2,3
Type2	VI	0.10	1,2,3

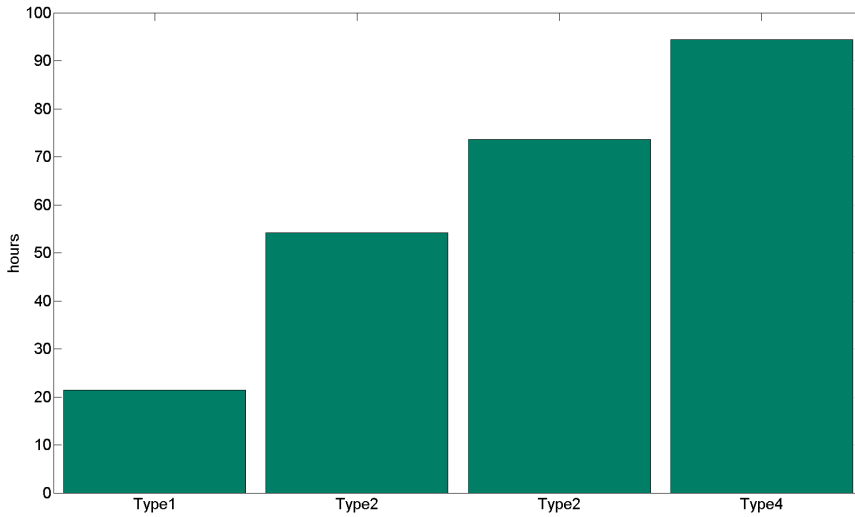


Figure 6.5: Average time spent in polygon
See table 6.1

Figure 6.6 shows the end positions of the particles from table 6.2. Just from visual inspection one can see that the speed of 0.10 m/s result in a bit more particles settling in the desired area. Again suggesting that the deeper the lobster are, the less the impact of ocean dynamics. If one compares the plot from section 6.3.1, figure 6.3, it is clear that including early settling greatly increases the number of particles settled in polygon.

6.4.2 Total time spent in sea ranching area

Figure 6.7 show the difference of time spent in ranching site by the two particle types.

Higher speed result in a larger amount of time spent in polygon.

6.5 Constant behaviour

To get a representation on older stage IV lobsters, on the hypothesis that they stay closer to the bottom, behaviours that would migrate to the bottom quicker

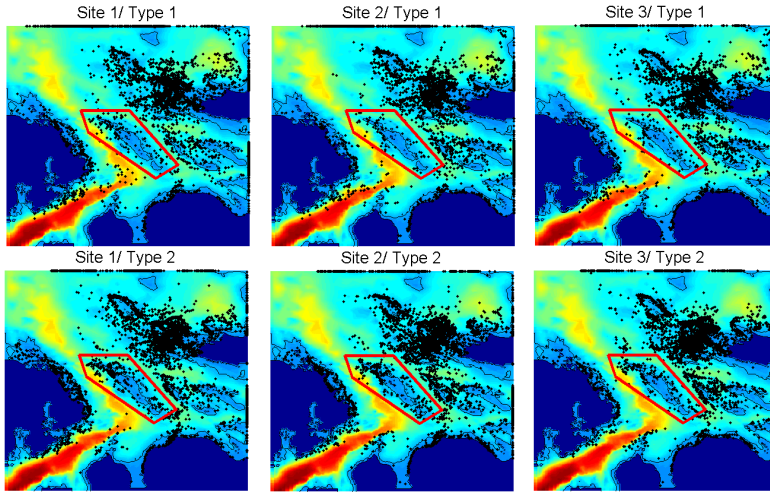


Figure 6.6: End positions
See table 6.2

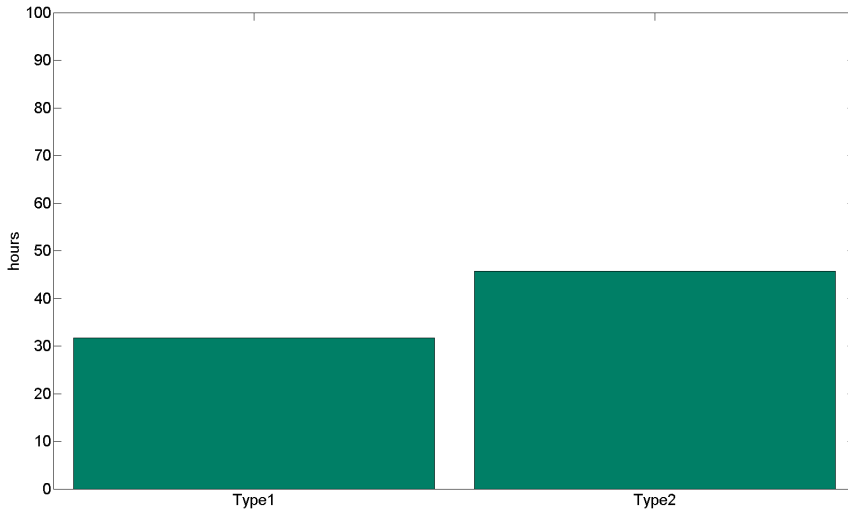


Figure 6.7: Average time spent in polygon [hours]
See table 6.2

were introduced. These were represented in constant vertical migrating (i.e non increasing) and with a fixed distance over the bottom. The behaviour simulation details are described in table 6.3. The speeds are the same as in section 6.4, while distances are chosen be 1m and 0.5m over bottom covering both the the deepest and second deepest layer of the model. Note that these simulations were conducted without early settling.

Table 6.3: Simulation 3 details

Name	Behavior	Max speed [m/s]	Distance over bottom [m]	Site
Type1	VC	0.05	-	1,2,3
Type2	VC	0.10	-	1,2,3
Type3	PC	-	1.0	1,2,3
Type4	PC	-	0.5	1,2,3

6.5.1 Settlement overview

Figure 6.8 shows the end positions of particles with constant vertical movement and figure 6.9 shows the end positions particles with constant height over ocean floor.

Undoubtedly the vertical profile with lobsters that keep a constant distance of 0.5m over the bottom result in the most particles settled at the sea ranching site. The constant vertical migration seem far better in terms of settlement at ranching site than the behaviour of increasing migration observed in figure 6.6.

6.5.2 Total time spend in sea ranching area

Total average time in polygon for the four constant particles types is shown i figure 6.10. These behaviour profiles have over 100 hours spent in polygon, more than any of the other, earlier simulated profiles. Again higher speed results in more hours spent in the desired area, while there is little difference between 1m or 0.5m over ocean floor. This is better illustrated in figures 6.11 and 6.12

Average times in polygon are shown in figure 6.11 for constant migration and 6.12 for constant position. The bars in the plot are grouped by releases and colored after speed/distance.

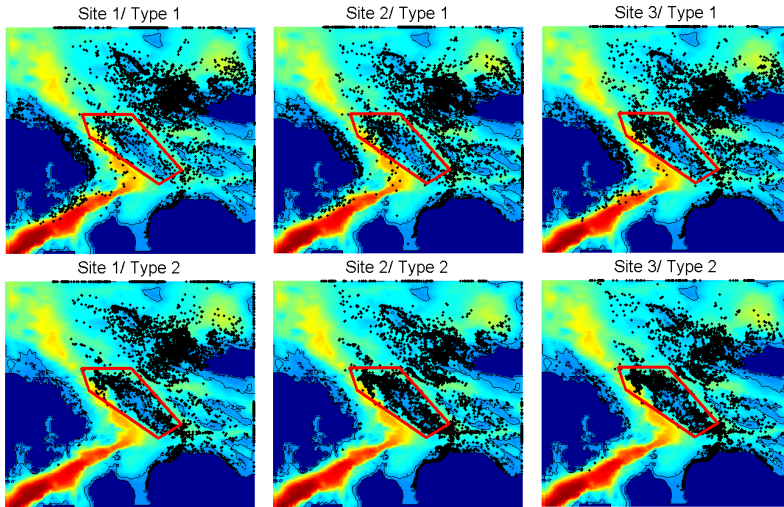


Figure 6.8: End position, constant vertical migration
See table 6.3

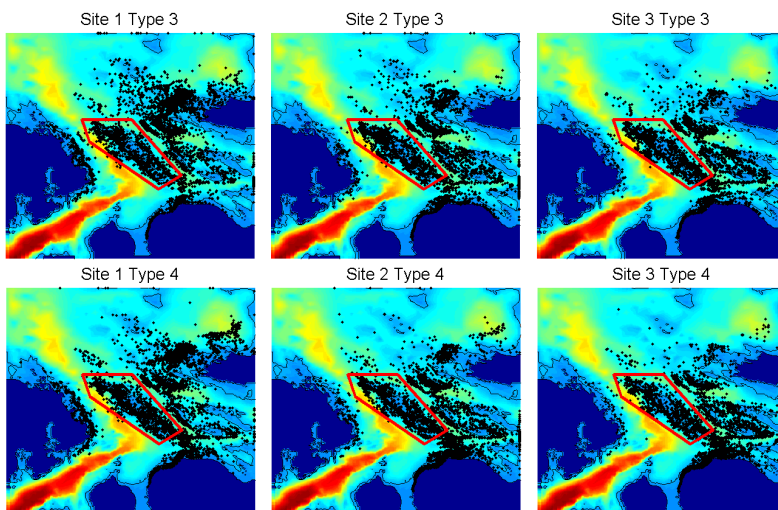


Figure 6.9: End position, constant position
See table 6.3

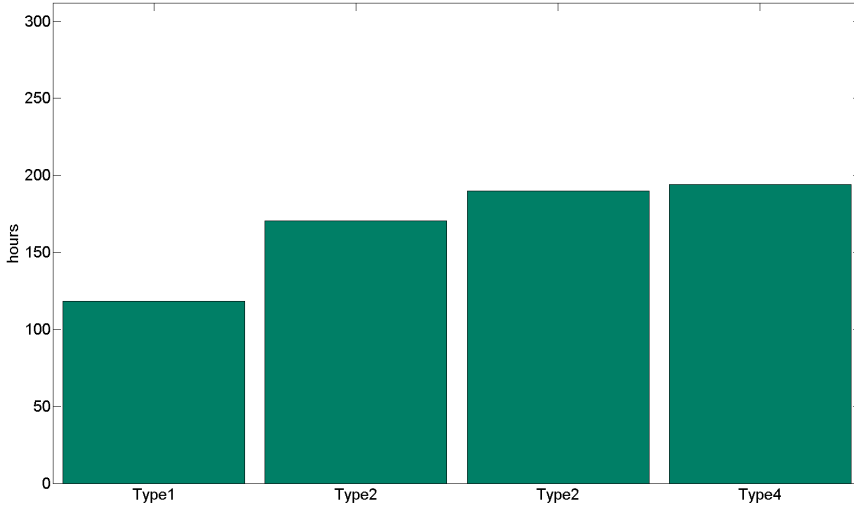


Figure 6.10: Average time in polygon, sorted by type
See table 6.3

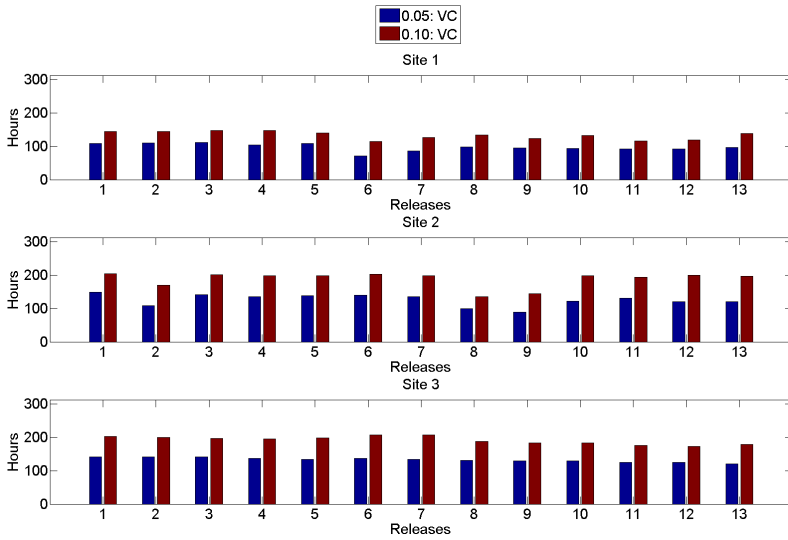


Figure 6.11: Average time spent in polygon, constant vertical
See table 6.3

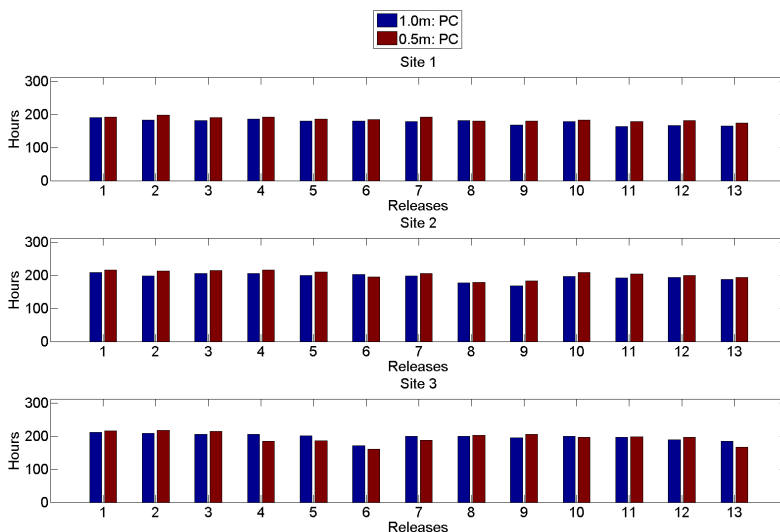


Figure 6.12: Average time spent in polygon, constant position over bottom
See table 6.3

6.6 Passive particles

Passive particles were released on all three sites. Figure 6.13 show the results.

These results are more positive than the ones presented in section 6.3. While figure 6.3 shows that close to none particles of passive behaviour are settled in the polygon, figure 6.13 show that the particles at least spend som time in the sea ranching area(on average about 20 hours).

6.7 Comparisons

This section presents some comparisons between different hebaviours.

6.7.1 Surface releases vs Bottom releases

The difference between surface and bottom releases were investigated. The release site used was 1(see figure 6.1 on page 33). The four different behaviours are shown in table 6.1. Figure 6.14 show percentage of total particles in polygon at the end

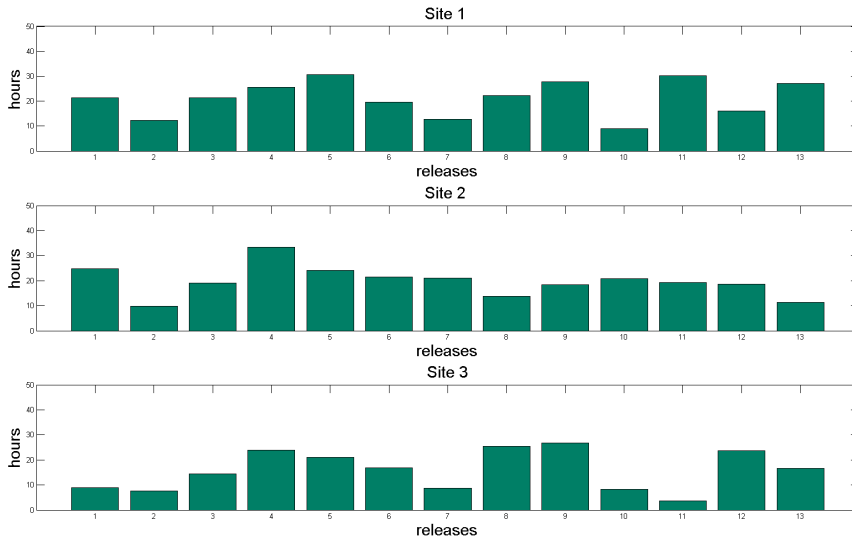


Figure 6.13: Average time spent in polygon, passive particles

of simulation. Because of the low percent values maximum y value in the plot is 50 % for increased visibility. Different behaviours are grouped together, depicted with the same color, top releases first. Data is also grouped into releases, 7 in this simulation (conducted every two hours from 1. May 0:00).

The figure 6.14 show that bottom releases, overall result in some more particles in the polygon. The trend is clear for Type 4, but the differences are smaller for particles with lesser vertical activity. One can also see that from most releases none of the passive particles stay in the area (presented as the darkest green color in the figure).

6.7.2 Early settling and no early settling

Figure 6.15 show the difference between early settling and no early settling for the vertical increasing behaviour profiles (VI), with speed 0.05 and 0.10.

There is a difference in time spent in polygon, but it is rather small.

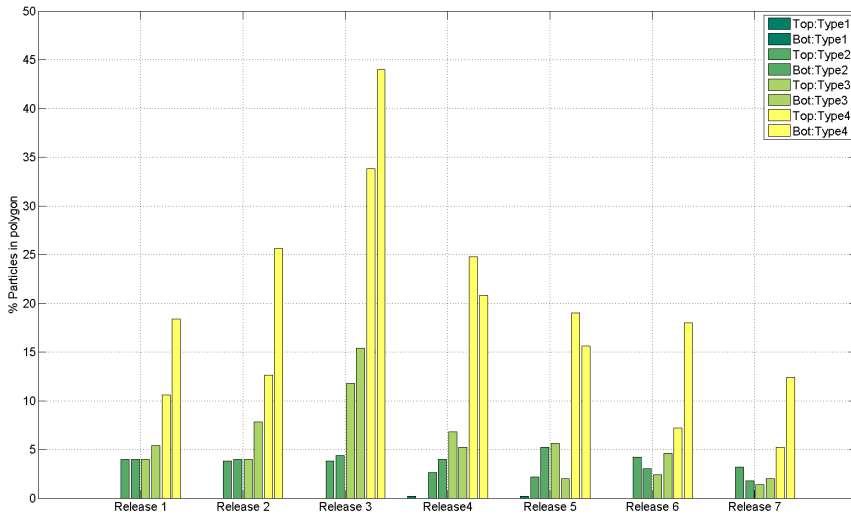


Figure 6.14: Top Vs Bottom releases
See table 6.1

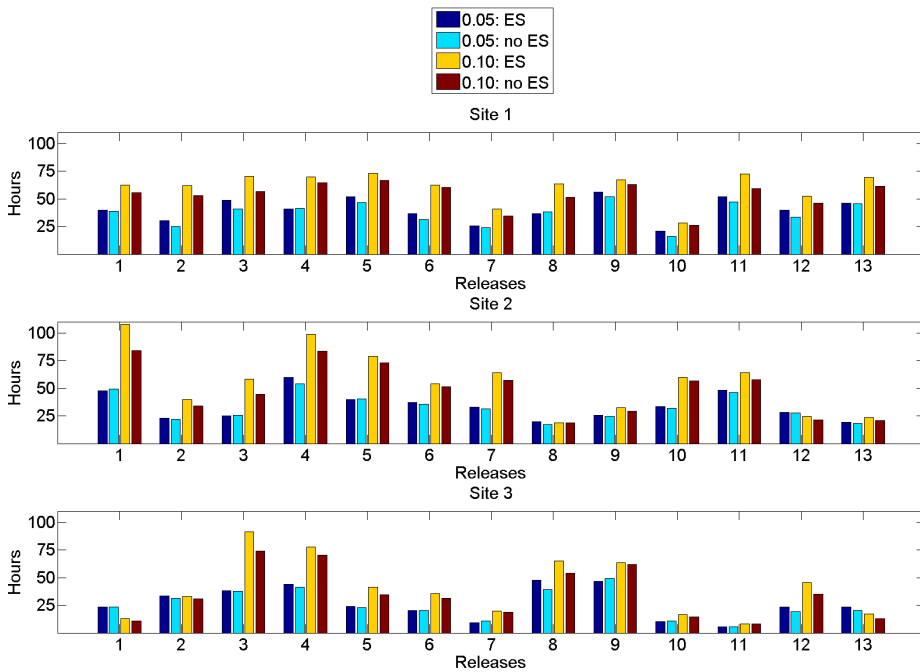


Figure 6.15: Vertical Increasing: early settling vs no early settling

6.7.3 Increasing vertical vs constant vertical

Figure 6.16 show the difference between vertical increasing and vertical constant behaviour, with speed 0.05 and 0.10 and no early settling.

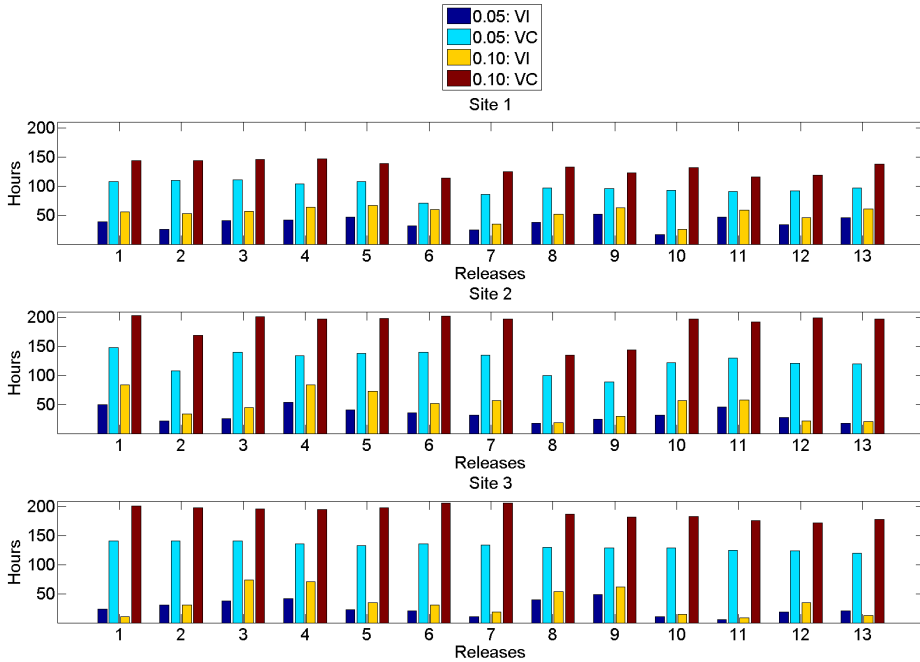


Figure 6.16: Increasing Vertical vs Constant Vertical

The difference between these two profiles is quite significant, at some releases resulting in 50% more time spent in desired area. The differences are strongest at release site 3.

6.8 Dispersal beyond model grid

Particles can leave the model grid area through four borders.

Figure 6.17 show where passive particles end up. Clearly most drift out of the model grid at the upper border. This trend is similar for all three sites.

Figure 6.8 show the number of particles leaving through each border for the vertical

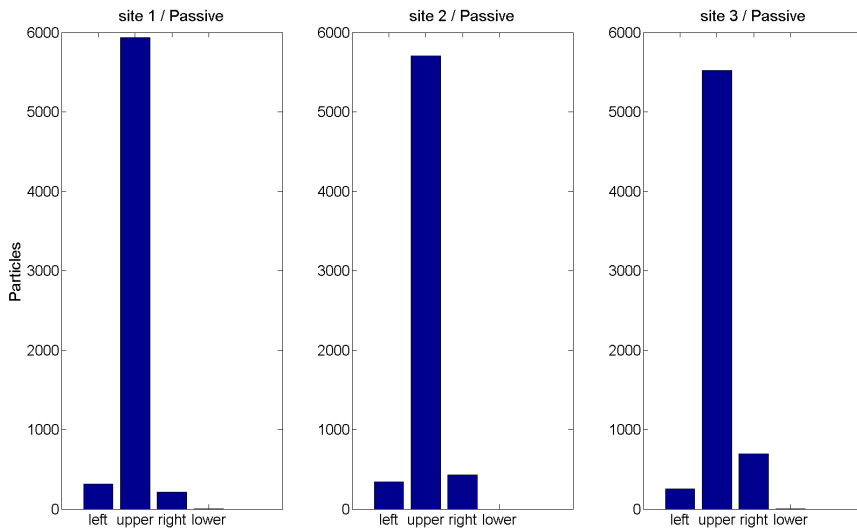


Figure 6.17: Border distribution: Passive

behaviour described in table 6.2.

In this case, less particles leave the grid area, but when they do it is usually through the right border.

6.9 Current

The following plots show current speed and angle at each site during the 24 hour period of releases. Red crosses mark the time the new release is conducted.

Figure 6.19 show the current angle and figure 6.19 show current speed in the bottom layer

Station 1 seem to have the smallest variation in angle as well as the lowest speeds.

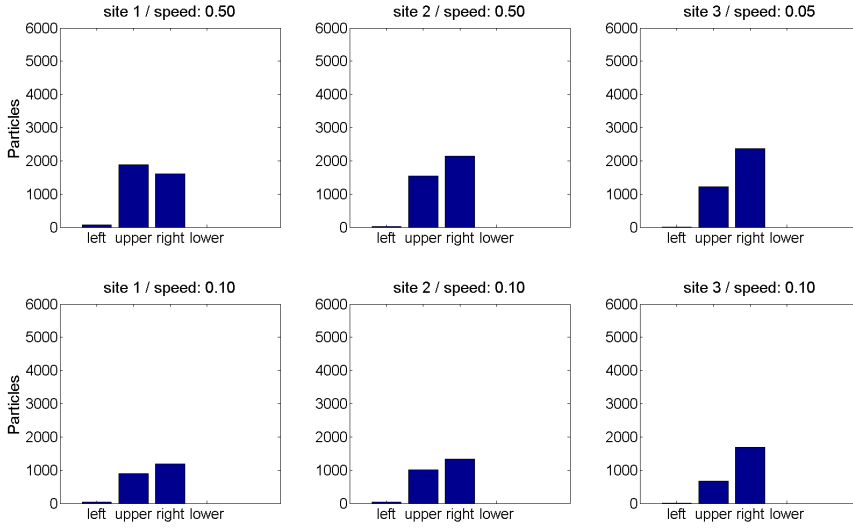


Figure 6.18: Border distribution: VI
See table 6.2

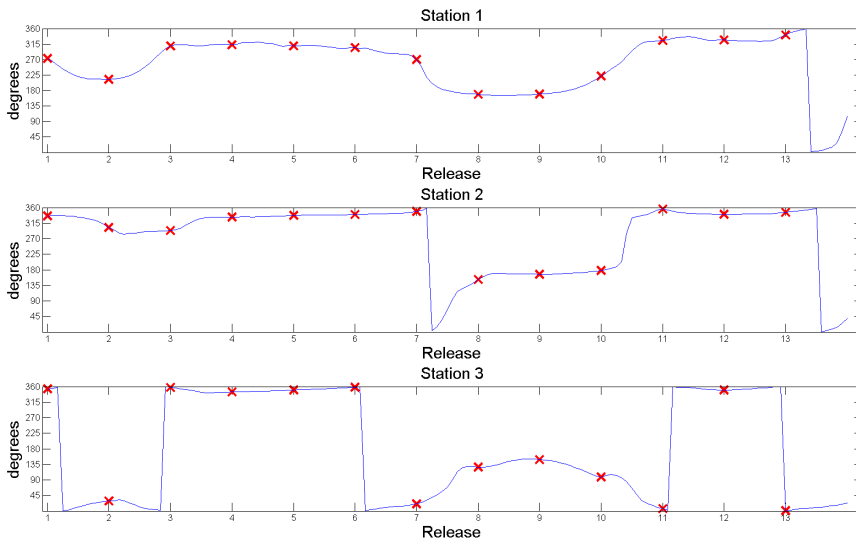


Figure 6.19: Station Angles

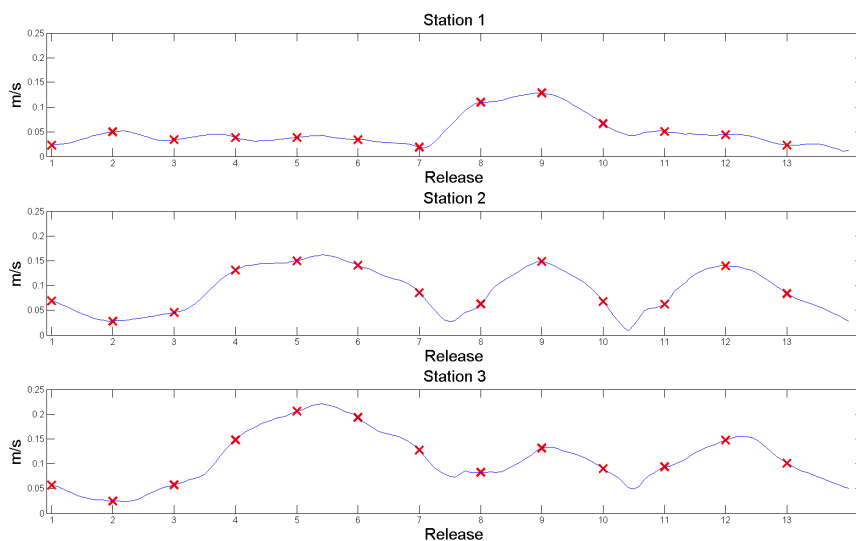


Figure 6.20: Station Speeds

6.10 Site and release time differences

Figure 6.21 shows the average hours spent in polygon by particles released at different sites. behaviours are passive, VI and VC, the last two with speeds of 0.05 m/s.

Passive and vertical increasing particles released at site 1 have the most time spent in the polygon. For the constant behaviour, site 3 is the best. The differences are however very small.

Figures 6.22, 6.23 and 6.24 show the average time spent in polygon by particles of type passive and vertical increasing for each release.

There seem to be a small trend that is different for each release site. Release 7, 10 and 11 (conducted 12 pm, 6pm and 8pm respectively) at station 3 are exceptionally bad, resulting in far less hours spent in polygon than the other releases. Release 10 at station 1 does also give less good results. Station 2 seems to have its "worst" releases at time 2am, 4am, 14pm and 16pm (release 2, 3, 8 and

Similar plots for constant vertical behavior were examined, but revealed no large differences in releases. One plot is included, figure 6.25, showing constant vertical movement and constant position for release site 1.

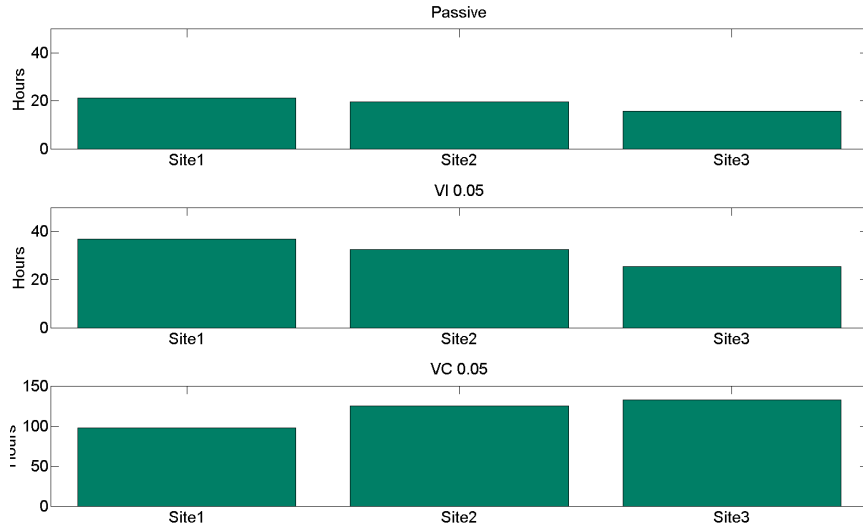


Figure 6.21: Station time in polygon averages

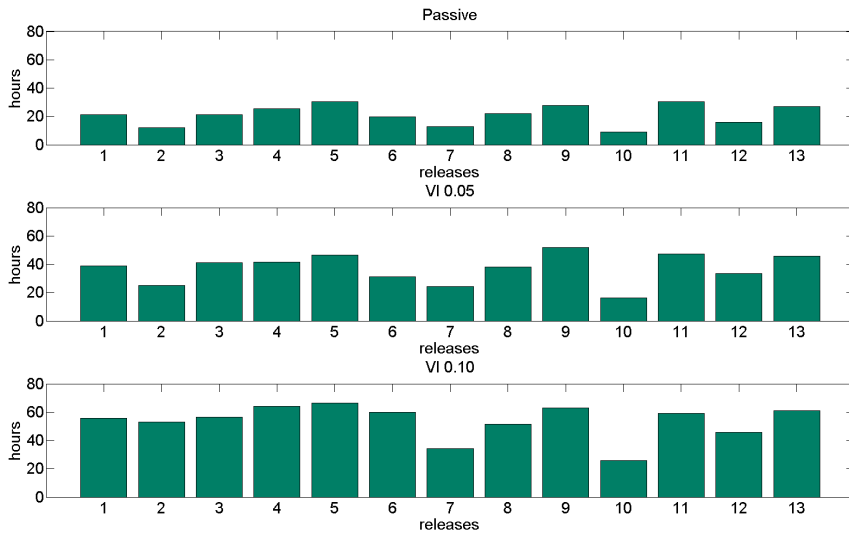


Figure 6.22: Station 1 time in polygon averages

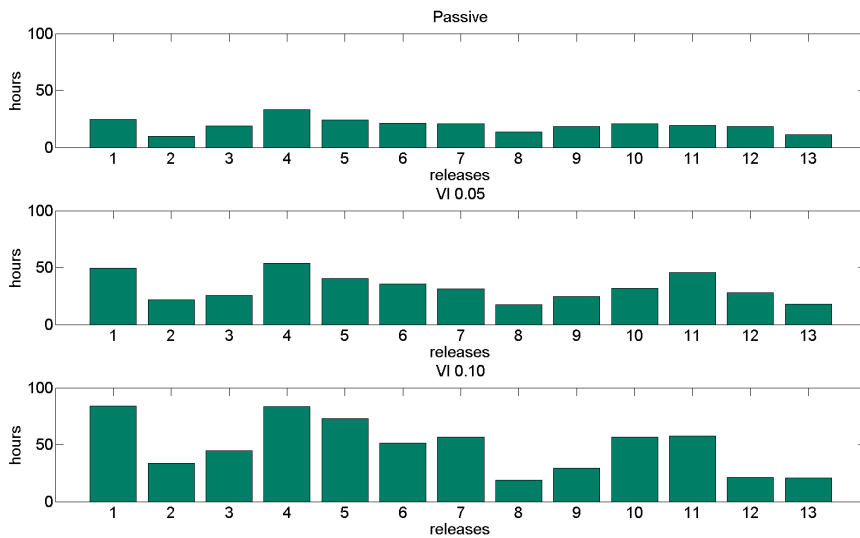


Figure 6.23: Station 2 time in polygon averages

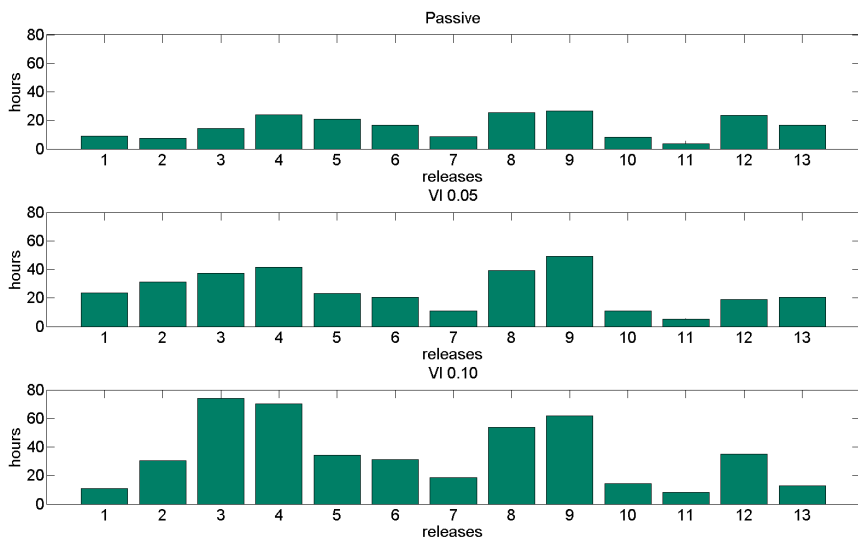


Figure 6.24: Station 3 time in polygon averages

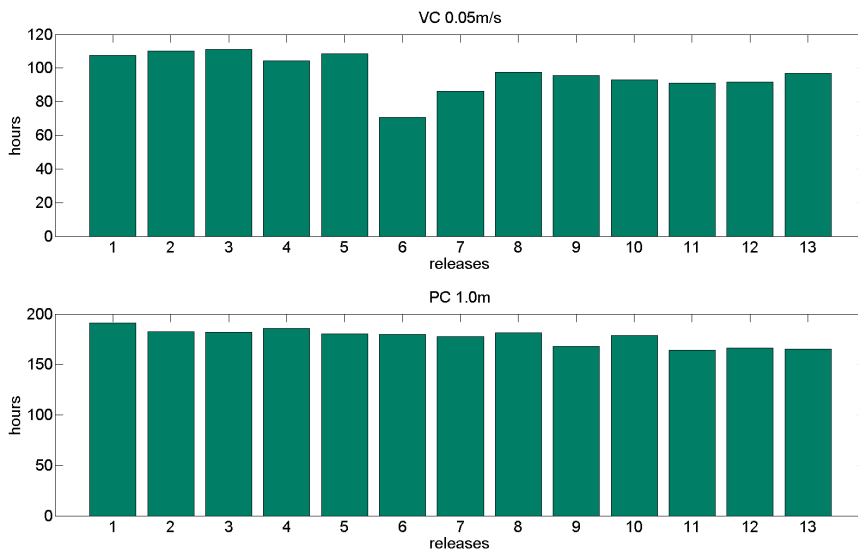


Figure 6.25: Station 1 time in polygon averages

Chapter 7

Discussion

The first section in this chapter will further discuss the results presented in chapter 6. In section two previously presented knowledge and research will be merged with the information gained by the simulations to suggest improvements for the stock enhancement strategy.

7.1 Simulations

Mainly the simulations have shown that there is a considerable difference between being a passive drifter and having the possibility to actively swim. The site differences have proven to be small, and the tidal effects elusive. This section presents an overall discussion to the different parameters from the simulations.

7.1.1 Behaviour

Different types of behaviours were chosen for the simulations to get some insight in to which parameters would affect the transport the most. The result show that staying close to the bottom result in the most desired scenario: with both most time spent in sea ranching site and most particles settled in the sea ranching site. But how does this compare to real life behaviour? Some studies already mentioned describe stage IV lobsters as pelagic, with sounding behaviour towards the bottom. One can argue that the increasing bias of downwards migration (VI) is

a fair assumption. Further it is hypothesised that older stage IV lobsters are more bottom-seeking than newly-molted stage IV lobsters, leading to the argument of waiting with the release until lobsters have accumulated some days into stage IV. In simulation terms the behaviour profile of constant height over bottom or constant vertical migration seems like an adequate simplification. Studies where lobsters have been released and recaptured successfully have involved larger juveniles, usually stage 6, and it is argued that successful releases should include older juveniles [33]. But rearing lobsters for a longer period result in higher costs, and as time to molt into older stages is longer for each stage, it increases the cost by a large amount. This increase of cost has to be weighted against survival rate increase of older juveniles contra young.

If the assumptions made in the simulations are somewhat correct, and the behaviour simplification realistic enough, it seems like releasing older stage IV lobsters is far better than releasing newly hatched. This period of elongated hatchery life is without doubt far less costly than rearing to stage V or VI.

7.1.2 Settlement and time spent in ranching site

The time spent by lobsters in the sea ranching site varied a lot between the different behaviour types. From about 5-25 hours as passive drifters to upto 200 hours with constant position over bottom. The behaviour of increased vertical movement, which as argued seems like the most realistic interpretation of a young stage IV lobster, resulted in roughly 30 hours on average for 0.05m/s speed and about 45 hours for speeds of 0.10 m/s. The constant vertical migration behavior resulted in close to 150 hours.

With Botero and Atema [34] and Cobb et al. [27] arguing that settlement occurs after 2-6 days in 20 degree water, 40 hours might be to little time. Then again, observations have been done of lobsters temporarily crawling at the bottom, as if to test the substrate, before swimming upwards again. If this is the case, the simulations are to some degree pessimistic as a stay at the bottom would reduce current-transport time.

Further the accuracy of the calculations of time spent in polygon is limited by the model recording rate. At 30 minute intervals, the accuracy of time is not great. For instance if a particle stayed most of the 30 minutes in the area, but moved out just at the last minute, this time would not be accounted for. Similarly if a particle has just drifted into the area the time spent in are would be largely

overestimated. Increasing the rate at which data is recorded would better the accuracy, but greatly increase the size of the data and cause troubles with memory and computation time. Therefore the time computations should be interpreted as an overall view and coarse estimate.

Settlement of lobsters in sea ranching site is correlated to the time spent in the polygon. Since most of the analysis was done on the particle-types without possibility of early settlement, one might argue that the settlement numbers in the desired area will be higher in reality.

7.1.3 Distribution patterns

As an observation to be drawn from the initial inspections of settlement plots from chapter 6, the end positions of particles in most of the simulations seem to cluster in an area north of the sea ranching site.

The plots showing where particles leave the model grid area show that Release site 3 seem to have less particles leaving through the upper left border than the other sites, but in turn more leaving through the right border.

7.1.4 Ocean Dynamics

Despite different behaviour profiles, there seem to be a common trend in the different release sites. For example, particles released at times 02:00, 12:00, 18:00 and 20:00 at site 3 seem to have the lowest time spent in polygon. Similarly releases at time 12:00 and 18:00 at site 1 are equally bad. Occurring twice a day, tidal activity might be the reason for this. It was hard to find evidence for any parameter (such as current angle or speed) being solely responsible.

7.1.5 Sites

The three sites show small differences in terms of how many particles that leave the area. For the particles that spend more time in the water column (passive and vertical increasing, site 1 seems to be better, although the differences are small. For constant vertical migration and constant position, sites have even smaller differences.

The results also revealed that releases at bottom instead of at surface are a little more beneficial in terms of reducing transport due to currents.

7.1.6 Improvements and further work

Initially it was hoped for the simulations to reveal something significant to be used as a inspiration for a improved release-pod. This could have been a current direction, time of day or something similar, yet it was not found. This section suggests what could have been done differently or in addition to get more functional results.

An option would be to chose more release sites to strengthen or invalidate the current results. At least two of each depths and/or placement relative to center or border of area should be tried.

The time period, stretching over two weeks is just enough for all particles to molt and settle at the bottom. However other periods could have been used in addition. The releasing period stretching from march to June gives a fair amount of days to choose from. Varying the simulation period could reveal patterns in the different release sites while increasing the release period could reveal that there indeed is a correlation of time of day and the number of particles settled in desired are.

Botero and Atema [34] observed behaviour where the lobster would stay at the bottom crawling for a short amount of time before returning to the water column. The study was done in a relatively shallow tank, and of the *H.americanus* species, so the results suffer from somewhat unrealistic conditions. However, this type of behaviour is not unthinkable. Regarding the simulations, one could chose a behaviour that had a possibility of temporal settlement at bottom. As mentioned earlier, this would probably reduce the amount of current transport.

Still one has to consider time against valid results. And since no clear parameter, like day or site, immediately stood out one can question the need of further simulations. If in the future more research on lobster behaviour will be available, more comprehensive simulations can be done with more concluding results.

7.2 Strategy improvement

Being observed numerous times, death by predators within the first half hour of release seem to be the biggest problem of the stock enhancement process as it is conducted today. This section will describe some ideas that might be worth looking into. Further suggestions based on the simulation results will be presented later in this section.

7.2.1 Predation avoidance

When it comes to predator-solutions the most important thing is cost specially since it cannot be said with certainty where the lobsters actually end up (carried far away in worst case), too much capital cannot be spent on predator-avoidance alone.

Solutions such as lowering a cage with a large cod together with the lobster pods would probably be a good solution in terms of predator avoidance, as it would scare away smaller fish. Ethically however it is challenging, and since one cod would be needed for each pot it is expensive and time-consuming.

All at once

Current practise is to open release pods at bottom, allowing lobsters to swim out when desired. This makes the emptying of the pod somewhat quick at start (limited by the opening size), and slower as the more indecisive lobsters are left inside. Previous trials have also shown larger fish, such as cod, swimming up to the opening of the release pod and consuming most of the released larvae.

One of natures great defence mechanisms is in the strength of numbers, seen in phenomenons such as swarms and schooling. The more lobsters released at once, the higher the number of survivors should be. Developing a mechanism for releasing juveniles all at once, could increase their chances of survival.

Impairing visual feeders by night releases

Mentioned earlier most of the young lobster's predators are diurnal. Many of these, being visual feeders, struggle more at finding food at night. The lobsters freezing

response when introduced to a predator (as observed in Johns and Mann [35] and argued for in Lawton [7]) might be a good solution in darkness, as it weakens the predators probability of spotting the lobster. One could imagine a mechanism that releases lobsters some time after dark, enabling the pods to be placed at day, to be gathered again later.

Predator intimidation

A master thesis, Trengereid [36], looked at lobster reaction when exposed to predator odors. More research is needed, yet the study found some increased shelter seeking reaction in lobsters exposed to odors in contrary to naive lobsters. The study suggest to train lobsters in the rearing facility, something that would be an inexpensive solution.

Sound is used to scare away fish from generators and turbines at sea to avoid killings and damaged equipment. One can imagine a similar solution where the lobster pods include som device for playing the sound. However intimidating sound might be specific to only one type of species, and harmless to another.

It is documented that fish learn, and adaptability to any intimidation method would occur after a while. But if used only at release, the lobsters would have time to find shelter long before any predator would learn the none threatening nature of the intimidation mechanism. However little research have been conducted on both sound and odors, making this could only only possible in the future

7.2.2 Simulation results

Clearly, more research is about biology and ecology of the lobster is needed in order to successfully and conclusively be able to improve stock enhancement and sea ranching processes. Based on the simulation results lobsters staying close to the bottom will spend more time in the sea ranching area. Releasing older postlarvae might therefore be a good solution. Releases at bottom seem to be advantageous in terms of transport out of area and should be practised in the future as well. Also night seems to be the best time in terms of predator avoidance

Chapter 8

Conclusion

It cannot be emphasized enough how much this work relies on research and data that itself is not satisfyingly conclusive. Clearly the main limitation of this study are the lack of biological data and behaviour observations. With this chink in ones armour (or shell if you want) exposed one also has to see the value of the results produced. Having one specific area to study, greatly reduces the problem and allows one to focus on something concrete. The dynamical model used has been applied to numerous similar studies, showing reliable results when compared to recorded data. Thus, if in the future any more knowledge on ecology and biology of the lobster is added to the pool of information currently available, simulations can be done far more accurately.

8.1 Conclusion

This thesis has described the process of using hydrodynamic models to gain information on the processes of sea ranching. Literature and previous research was used to create several plausible behaviour models of stage IV lobsters. These models were used together with a fine-scale hydrodynamic model to conduct several simulations. Results were analysed in terms of spreading patterns, settlement rates and time, with the aim of trying to correlate the patterns to some environmental parameter such as time of day or current speed.

The information gathering process revealed that little research on the matter of lobster behaviour existed. The amount information available resulted in simula-

tions that mainly suggested that the transport of lobsters is depended on depth, and that keeping close to the bottom result in less lobsters transported out of the sea ranching site. This suggest that lobster should be released at an older age, at least a couple of days into stage IV, but preferably after reaching stage V.

The simulations have enhanced the perception that the practise of releasing lobsters at the bottom is advantageous to releases at surface. Bottom releases seem to be preferable not only due to reduction of predator intervention, but also in terms of less hydrodynamic transport.

As for the release sites little differences were observed. In most simulations site 1 was better than site 2 which again was better than site 3, but these variations were small. The average time spent in polygon varied over the 24 hour release period, suggesting that some ocean mechanism is responsible.

More research and simulations are needed to draw a certain conclusion. Simulations with different time periods as well as more release sites should be conducted to further investigate the trends observed at different release times. When more information on lobster behaviour is available, more authentic simulations can be done.

Appendix A

Acronyms an Glossary

Benthic Of or relating to or happening on the bottom under a body of water

EBP Early benthic phase

Pelagic Living at or near the surface of the ocean

Postlarva Stage in the development of Crustaceans. Here referring to the fourth stage of lobster development

Phototaxis The movement of an organism or a cell toward or away from a source of light

Bibliography

- [1] Frank Nicosia and Kari Lavalli. Homarid lobster hatcheries: Their history and role in research, management, and aquaculture, 1999. URL <http://spo.nwr.noaa.gov/mfr612/mfr6121.pdf>.
- [2] The National Lobster Hatchery. The national lobster hatchery |a marine conservation charity, 2016. URL <http://www.nationallobsterhatchery.co.uk/whats-it-all-about/>.
- [3] Lov om havbeite, 2000. URL <https://lovdata.no/dokument/LTI/lov/2000-12-21-118>.
- [4] Bruce Phillips. *Lobsters: Biology, management, Aquaculture and fisheries*. Wiley-Blackwell (an imprint of John Wiley & Sons Ltd), Ames, Iowa, USA, 06 2006. ISBN 9781405126571.
- [5] Eric R. Annis. Temperature effects on the vertical distribution of lobster postlarvae (*homarus americanus*), 11 2005. ISSN 0024-3590.
- [6] A Lillis and PVR Snelgrove. Near-bottom hydrodynamic effects on postlarval settlement in the american lobster *homarus americanus*, 02 2010. ISSN 0171-8630.
- [7] Peter Lawton. Chapter 4. postlarval, juvenile, adolescent, and adult ecology. In Kari Lavalli, editor, *Biology of the lobster*, pages 47–88. Elsevier BV, 1995. ISBN 9780122475702. doi: 10.1016/b978-012247570-2/50026-8.
- [8] St.Lawrence Global Observatory. American lobster - life cycle - ogsl. URL <https://slgo.ca/en/lobster/context/cycle.html>.
- [9] J. M. Carlberg, J. C. Olst, and R. F. Ford. A comparison of larval and juvenile stages of the lobsters *homarus americanus*, *homarus gammarus*, and their hybrid1. *Proceedings of the annual meeting - World Mariculture Society*,

- 9(1-4):109–122, 02 2009. ISSN 0164-0399. doi: 10.1111/j.1749-7345.1978.tb00236.x.
- [10] LL.D. Gruffydd, Rebecca A. Rieser, and D. Machin. A comparison of growth and temperature tolerance in the larvae of the lobsters *homarus gammarus* (l.) and *homarus americanus* h. milne edwards (decapoda, nephropidae). *Crustaceana*, 28(1):23–32, 01 1975. ISSN 0011-216X. doi: 10.1163/156854075x00838.
- [11] P A Prodøhl, K E Jørstad, A Triantafyllidis, V Katsares, and C Triantaphyllidis. European lobster -*homarus gammarus*. Technical report, 2007. URL http://www.imr.no/genimpact/filarkiv/2007/07/european_lobster.pdf/en.
- [12] John P. Mercer, R. Colin A. Bannister, Gro I. van der Meeren, Valerie Debusse, David Mazzoni, Steve Lovewell, Ronan Browne, Adrian Linnane, and Brendan Ball. An overview of the lear (lobster ecology and recruitment) project: Results of field and experimental studies on the juvenile ecology of *homarus gammarus* in cobble, 2001. ISSN 1323-1650.
- [13] Adrian Linnane, Brendan Ball, John P. Mercer, Ronan Browne, Gro van der Meeren, Halldis Ringvold, Colin Bannister, David Mazzoni, and Brian Munday. Searching for the early benthic phase (ebp) of the european lobster: a trans-european study of cobble fauna. *Hydrobiologia*, 465(1/3):63–72, 2001. ISSN 0018-8158. doi: 10.1023/a:1014547618888.
- [14] C.K Govind and Joanne Pearce. Mechanoreceptors and minimal reflex activity determining claw laterality in developing lobsters. *Journal of Experimental Biology*, 171(1):149–162, 06 1992.
- [15] Gordon Milligan. Common lobster (*homarus gammarus*), 05 2016. URL <https://www.flickr.com/photos/el-milligano/15496784819>.
- [16] Gro I van der Meeren. Predation on hatchery-reared lobsters released in the wild. *Canadian Journal of Fisheries and Aquatic Sciences*, 57(9):1794–1803, 09 2000. ISSN 0706-652X. doi: 10.1139/f00-134.
- [17] – 2015. Sea ranching, 06 2013. URL <https://www.daf.qld.gov.au/fisheries/aquaculture/overview/types/sea-ranching>.
- [18] Gro I. van der Meeren. Out-of-water transportation effects on behaviour in newly released juvenile atlantic lobsters *homarus gammarus*, 01 1991. ISSN 0144-8609.

- [19] A.-L. Agnalt, G.I. van der Meeren, K.E. Jørstad, H. Næss, E. Farestveit, E. Nøstevold, T. Svåsand, E. Korsøen, and L. Ydstebø. Stock enhancement of european lobster (*homarus gammarus*): a large-scale experiment off south-western norway (kvitsøy), 1999.
- [20] Patricia Rooney and J. Stanley Cobb. Effects of time of day, water temperature, and water velocity on swimming by postlarvae of the american lobster, *homarus americanus*. *Canadian Journal of Fisheries and Aquatic Sciences*, 48(10):1944–1950, 10 1991. ISSN 0706-652X. doi: 10.1139/f91-231.
- [21] Gro I. Van der Meeren. Initial response to physical and biological conditions in naive juvenile lobsters *homarus gammarus* l, 12 1993. ISSN 0091-181X.
- [22] Kenneth M. Leber, Shuichi Kitada, H.L. Blankenship, and Terje Svaasand, editors. *Stock enhancement and sea Ranching: Developments, pitfalls and opportunities*. Blackwell Science, United Kingdom, 07 2004. ISBN 9781405111195.
- [23] O.P Pedersen, M Aschan, T Rasmussen, K.S Tande, and D Slagstad. Larval dispersal and mother populations of *pandalus borealis* investigated by a lagrangian particle-tracking model. *Fisheries Research*, 65(1-3):173–190, 12 2003. ISSN 0165-7836. doi: 10.1016/j.fishres.2003.09.014.
- [24] O.P. Pedersen, K.S. Tande, and D. Slagstad. A model study of demography and spatial distribution of *calanus finmarchicus* at the norwegian coast. *Deep Sea Research Part II: Topical Studies in Oceanography*, 48(1-3):567–587, 01 2001. ISSN 0967-0645. doi: 10.1016/s0967-0645(00)00127-2.
- [25] Lewis S. Incze and Christopher E. Naimie. Modelling the transport of lobster (*homarus americanus*) larvae and postlarvae in the gulf of maine, 03 2000. ISSN 1054-6006.
- [26] MS Windows NT kernel description. <http://www.sinmod.no/>. Accessed: 2016-06-31.
- [27] J. S. Cobb, D. Wang, D. B. Campbell, and P. Rooney. Speed and direction of swimming by postlarvae of the american lobster, 01 1989. ISSN 0002-8487.
- [28] Folke Mehrstens, Mareike Stolpmann, Friedrich Buchholz, Wilhelm Hagen, and Reinhard Saborowski. Locomotory activity and exploration behaviour of juvenile european lobsters (*homarus gammarus*) in the laboratory. *Marine and Freshwater Behaviour and Physiology*, 38(2):105–116, 06 2005. ISSN 1023-6244. doi: 10.1080/10236240500104101.

- [29] Bernard Boudreau, Yvan Simard, and Edwin Bourget. Influence of a thermocline on vertical distribution and settlement of post-larvae of the american lobster *homarus americanus milne-edwards*. *Journal of Experimental Marine Biology and Ecology*, 162(1):35–49, 10 1992. ISSN 0022-0981. doi: 10.1016/0022-0981(92)90123-r.
- [30] G. P. Ennis. Behavioral responses to changes in hydrostatic pressure and light during larval development of the lobster *homarus americanus*, 02 1975. ISSN 0015-296X.
- [31] Anna B Neuheimer and Christopher T Taggart. The growing degree-day and fish size-at-age: The overlooked metric, 02 2007. ISSN 0706-652X.
- [32] CH Katz, JS Cobb, and M Spaulding. Larval behavior, hydrodynamic transport, and potential offshore-to-inshore recruitment in the american lobster *homarus americanus*, 1994. ISSN 0171-8630.
- [33] Gro I. van der Meeren. Livets gang, 04 2015.
- [34] Leonor Botero and Jelle Atema. Behavior and substrate selection during larval settling in the lobster *homarus americanus*, 02 1982. ISSN 0278-0372.
- [35] P.M. Johns and K.H. Mann. An experimental investigation of juvenile lobster habitat preference and mortality among habitats of varying structural complexity, 08 1987. ISSN 0022-0981.
- [36] Henrik Trengereid. Shelter seeking and competitive behavior in hatchery reared juvenile european lobster (*homarus gammarus*) exposed to predator odors. Master’s thesis, University of Bergen, Department of Biology, 2012.