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**Faculty of Natural Resources and Agricultural Sciences**

# Habitat preference of *Neogobius Melanostomus* in the Baltic Sea

– Habitat modelling of an invasive species

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# Habitat preference of *Neogobius Melanostomus* in the Baltic Sea

*Neogobius melanostomus* och dess habitatval I Östersjön

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# Abstract

Round goby, *neogobius melanosotmus*, is an invasive fish that has spread to the Baltic Sea from the Black sea. The invasion is most likely an effect of transport with ballast water. So far little is known of the impact of round goby in the invaded area, but  changes in the food web structure have been observed in the Baltic Sea. In this study the habitat preference of round goby was examined using GAM-modelling and thereafter maps over predicted occurrence were created to see its capacity of further spreading in the Baltic Sea. Monitoring data were gathered from the Baltic Sea, minus the Gulf of Bothnia. Variable data were gathered from rasters via ArcMap, with complementing data for depth measured during monitoring. The result of GAM-modelling shows  that the round goby prefers areas close to shipping traffic, with a low percentage in slope, shallow waters, moderately exposed areas and above for wave exposure, with a salinity up to 8 psu. The maps over predicted occurrence shows a probable continued spread along the shallow coasts in the monitored area. The results support earlier knowledge of round goby; however, as the fish spreads further in the Baltic Sea the relationship with other environmental variables may change as it is still competing to find its place in the ecosystem. As the fish has capacity to spread further, more knowledge of how to hinder this invasive fish is needed.

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# 1 Introduction

Invasive species, defined as “those non-native species that threaten ecosystems, habitats or species” is a growing issue in aquatic environments (Bax *et al.*, 2003; Pejchar & Mooney, 2009). Transport of invasive species with human vectors, such as ballast water in ships, have increased in the last decades (Panov & Caceres, 2007). As the ships get more well-managed the likelihood of organisms surviving the journey increase as they find the spaces more hospitable (Bax *et al.*, 2003). Marine invasive species are a threat to biodiversity on both regional and national level, which needs to be dealt with in a global cooperation (ibid.).

Round goby (*Neogobius melanostumus*) is an invasive fish which has spread to several different regions in the world, such as North America and Europe, from the Black and Caspian Sea (Kornis *et al.*, 2012). Round goby was first observed in the Gulf of Gdansk, Baltic Sea in 1990, and it was probably transported there with ballast-water from the Black Sea (Sapota, 2004). In 2011 it had been found along the coast of the Baltic Sea in Sweden, Finland, Latvia, Estonia, Denmark and Germany (Sokołowska & Fey, 2011). The round goby is believed to prefer shallow water and is highly adaptable with a high tolerance to different ranges of salinity, oxygen and temperature (Kornis *et al.*, 2012). However, there are no known populations in full ocean habitat (ibid.). The tolerance of a wide range of environmental variables could be the explanation of the wide spread of Round goby in the Baltic Sea and other waters (Sokołowska & Fey, 2011).

The impact of the round goby in the invaded waters are still not fully known, however it has earlier proven to have a negative influence on native species (Kornis *et al.*, 2014). In the upper St. Lawrence River, USA, the round goby has had a high impact on the macroinvertebrate community, causing a decrease in diversity, and most noticeable a decrease in biomass of the gastropods in the area (Kipp & Ricciardi, 2012). Since the introduction of the round goby in the Baltic Sea, it has been found in the stomachs of cod and turbot in shallow water in the Gulf of Gdansk. This changes the food web structure, creating a new energy-pathway from mussels to top predators have been formed although the consequences are not clear (Almqvist *et al.*, 2010).

A way to understand the ecological mechanisms in an ecosystem is to model a species relationship to the environment variables (De Knegt *et al.*, 2010). Using a species-environment analysis has earlier proven effective as a research tool and a method to forecast possible distributions of organisms (Guisan & Zimmermann, 2000). A statistical approach to such an analysis is generalized additive modelling (GAM) which is suitable for modelling fish to habitat-dependence (Zhao *et al.*, 2014). This is because GAM allows the modelling to be flexible, with both linear and non-parametric relationships (Jowett *et al.*, 2007).

In this report different environmental factors were evaluated to predict the potential distribution of round goby in the Baltic Sea. The habitat variables were chosen based on earlier knowledge of the round goby´s biology and variables that have earlier proven important in fish-habitats. Data from the Baltic Sea were used to statistically model the presence/absence of round goby. The aim was to develop a predictive model of its distribution to aid further understanding of the effects on the Baltic Seas ecosystem.

# 2 Method

## 2.1 Occurrence

Monitoring data (see figure 1) were gathered from the research project BONUS INSPIRE (INSPIRE, 2015), Swedish national and regional environmental coastal monitoring programs registered in KUL, a database of coastal fish from the Swedish University of Agriculture Sciences (Swedish University of Agricultural Sciences, 2015) and fish monitoring surveys from Latvia by the Institute of Food Safety, Animal Health and Environment "BIOR" (unpublished data, Laura Briekmane, BIOR, Latvia). The monitoring in this study is geographically restricted to the Baltic Sea without the Gulf of Bothnia and only the westernmost parts of the Gulf of Finland (see figure 2). This was done to avoid false absence since the fish is yet to spread to that area, and it is uncertain if this is due to unsuitable habitat or lack of time. All nets used for monitoring were multi-mesh gillnets, INSPIRE used Extended Nordic gillnets, data from KUL were monitored using Nordic multi-mesh nets (Andersson, 2009) and the Latvian data were gathered with Coastal Survey Nets. From the database KUL more monitoring data in the Baltic Sea than used were available; however they used different monitoring-methods and were therefore excluded.

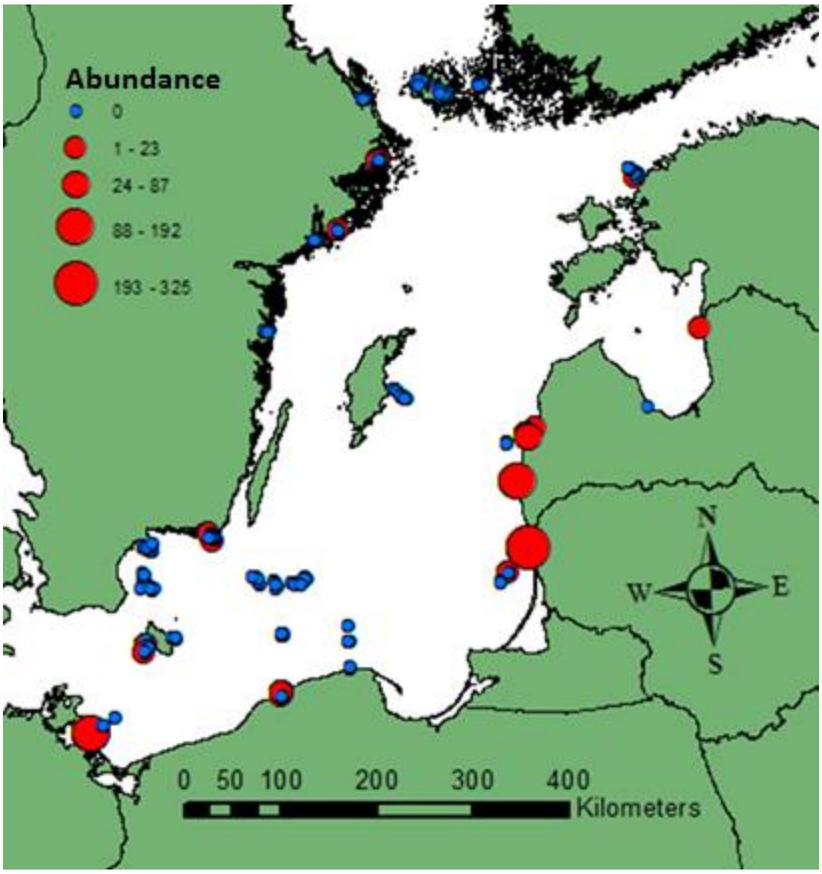

**Figure 1** *Monitoring stations marked in red and blue. Red locations have presence of round goby, and the blue locations have absence. The size of the red locations depends on abundance of round goby, see the legend. Some locations are overlapping and in some locations there are stations with presence beneath the stations with absence.*

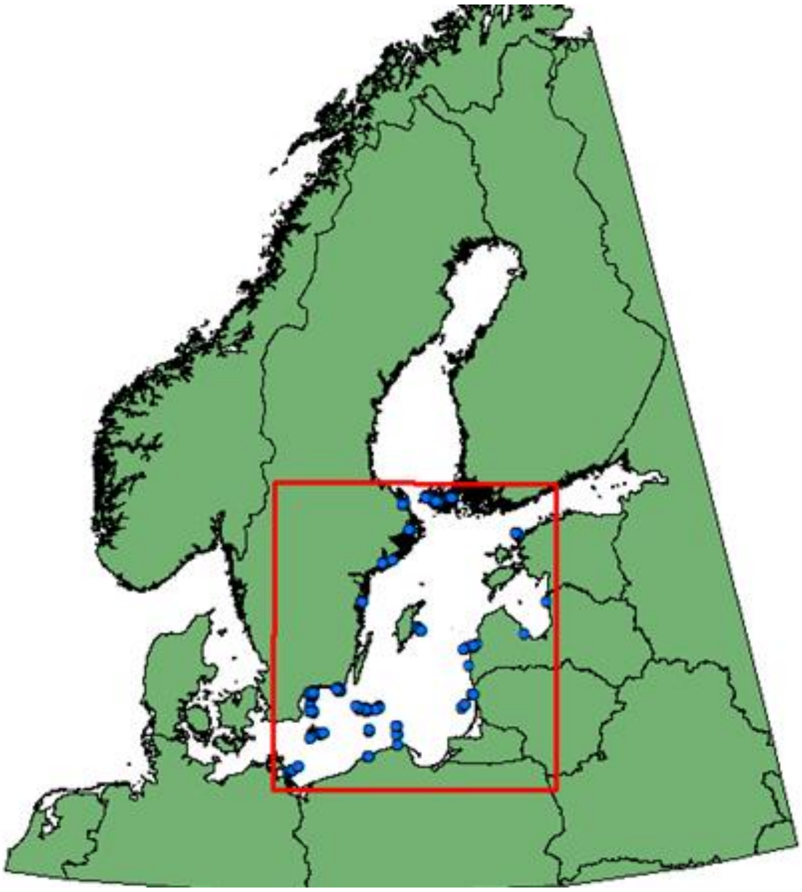

**Figure 2** *The red box gives the boundaries of the investigated area in this study*

## 2.2 Explanatory variables

Based on existing knowledge of round goby biology and previous habitat modelling for other fish species potential explanatory variables were identified. Six explanatory variables were used in the statistical modelling: distance to shipping traffic, salinity, slope, depth, wave exposure and bottom substrate. The occurrence of round goby is believed to be associated with shipping traffic and this is therefore an included possible explanatory variable (Kornis *et al.*, 2012). Round goby has a high tolerance to salinity but is absent in fully marine waters and most freshwater systems (ibid.). Hence it can be suspected that salinity might be a limiting factor despite its high tolerance. Slope, depth, wave-exposure and bottom substrate has earlier proven important in studies of fish habitat preference (Bergström *et al.*). The variables used in this project (except wave exposure) were gathered as raster layers produced by HELCOM; BALANCE, "Baltic Sea Management – Nature Conservation and Sustainable Development of the Ecosystem through Spatial

Planning" (HELCOM, 2015a) and AIS, "Automatic Information System" (HELCOM, 2015b).

The raster of wave exposure ($m^2$) was produced by a specific software, Waveimpact (Isæus, 2004). The raster has the resolution 25*25 meters. Wave exposure is categorised depending on the values as shown in table 1. Exact values were run in the model and the categories are used for interpretation and discussions of the results.

Table 1. *The different categories of wave-exposure according to Wennberg and Lindblad (2006)*

| Values in the continual raster ($m^2/s$) | Wave exposure |
|---|---|
| 1-1 200 | Extremely sheltered |
| 1 200-4 000 | Very sheltered |
| 4 000-10 000 | Sheltered |
| 10 000-100 000 | Moderately sheltered |
| 100 000-500 000 | Moderately exposed |
| 500 000-1 000 000 | Exposed |
| 1 000 000-5 000 000 | Very exposed |

Data for density of shipping traffic in the Baltic Sea equipped with an AIS (Automatic Identification System) was gathered from HELCOM AIS (HELCOM, 2015b). The raster of shipping traffic density was reclassified, cells with high density of shipping traffic (a density of 50 and higher) were classified to ones, and cells with values below 50 were classified as NoData. Another raster was reclassified so that cells placed on water were classified as one and cells placed on land were classified as zero. The two reclassified rasters; land and water and density of shipping traffic, were then used in the tool *Cost distance* in ArcMap. The tool calculates the least costly way between two cells. The raster of land and water was used to create the new raster with cell-values of cost distance (in the water-cells). In this case each cell shows cost distance to shipping traffic, and the cost distance-values can directly be translated to meters. The final raster had a resolution of 2235.76*2253.76 meters.

The raster of salinity shows bottom-water salinity in a resolution of 5*5 km (Al-Hamdani *et al.*, 2007). The depth raster shows water depth in meters and has a resolution of 200*200 meters (ibid.). Slope is given in percentage and has a resolution of 200*200 meters (ibid.). The sediment-raster is divided into five categories, (1) bedrock, (2) hard bottom complex, (3) sand, (4) hard clay and (5) mud with a resolution of 200*200 meters (ibid.).

Four layers, bathymetry, slope, bottom substrate and distance to shipping traffic, did not cover all the monitoring stations, since many of the stations are situated close to coast and there is a slight mismatch in the extent of the rasters in relation to the coastline. Depth, sedimentation and distance to shipping traffic were therefore expanded by one cell around the edges using the tool *Expand* in ArcMap. Before expanding the distance to shipping traffic raster, it was converted to an integer, which means that the values were reclassified to whole numbers. Slope could not technically be reclassified to an integer raster. Instead, data were manually extracted from ArcMap by using the same value as the closest raster-square to the points where data could not be collected.

The chosen variables were applied as layers in ArcMap in raster-format. Data covering the locations for monitoring were added from Excel with coordinates as point-locations. With the tool *Extract multi values* to point in ArcMap information about each variable was gathered for the fishing stations. These data were used together with water depth information gathered at the fishing stations and collated in an Excel file also including abundance of round goby per station.

## 2.3 Statistical analysis

To analyse the habitat preference of round goby the method generalised additive modelling (GAM), was implemented. GAM is a statistical modelling approach that combines non-parametric smoothing functions of selected variables with linear effects for other explanatory variables (Sundblad, 2010). The data gathered for the environmental variables were imported into Brodgar (Highland Statistics Ltd, 2013), an interface to the statistical programme R (The R foundation). The continuous variables were then added as non-parametric with a k-value of three (the amount of turns the relation can take). Sediment was added as a categorical class. Both binomial (presence/absence) and quasi-poisson (abundance) models were constructed, since zero-inflated data can sometimes be better modelled using presence-absence models. The wave-exposure index was log-transformed because of its skewed distribution.

Backward-selection of variables was used to select the best model. At first all the variables were run with the model. In each run, the variable with lowest p-value was removed and the model was run again. It was repeated until only variables with significant values ($P<0.05$) remained. This was done for the two distribution models. $D^2$, explained deviance, was used to describe the explanatory power of the final models. Partial response curves were produced to enable visual examination of response to individual environmental variables.

## 2.4 Predicted occurrence

Based on the partial response curves a map showing the predicted occurrence was created. The cells in the rasters of the significant variables were reclassified to ones and zeros, where one corresponds to values that showed probable occurrence (partial response curve above 0), and zeros where were there was no probable occurrence (partial response curve below 0). The tool *Times* in ArcMap, which multiplies rasters cell by cell, was used to multiply the rasters for the significant variables from each model run depending on distribution. Cells with the value one multiplied by other cells with the same value are left with a value of one in the new raster, and the rest become cells with the value zero. In the new raster cells have a value of one only if all the significant variables have predicted occurrence for the round goby according to the partial response-curves in that location. This new raster was then used to present a map of predicted occurrence of round goby in the Baltic Sea.

# 3 Results

A total of 603 monitoring-stations were analysed in this study. In 73 of these round goby was present, with an average abundance of 3.78 individuals in the stations where presence was found. The prevalence was 0.138.

## 3.1 Descriptive statistics

Table 2 shows the range of variable data for monitoring stations and the total range of variable data for the area. The data gathered where monitoring has occurred does not cover the total range of available values in the raster used for the environmental variables. In table 3 the number of monitoring stations per category of sediment and absence/presence of round goby is shown. The bottom substrate sand was both best covered by the monitoring and had the highest amount of round goby presence.

Table 2. *Ranges of data for environmental variables used in the statistical modelling*

| **Variables** | **Range of variable data for the monitoring stations** | **The total range of variable data in the researched area (see figure 2)** |
|---|---|---|
| Distance to shipping traffic | 0-3900 m | 0-63 000 m |
| Salinity | 4.55-12.6 psu | 3.11-33 psu |
| Slope | 0-4.78% | 0-50.5% |
| Depth | 1-80 m | 0-460 m |
| Wave exposure | 11-969 000 $m^2/s$ | 0-107 0000 $m^2/s$ |

Table 3. *Number of stations covering the different bottom substrate classes, including where there was round goby presence and absence*

| | **Bedrock** | **Hard bottom-complex** | **Sand** | **Hard clay** | **Mud** |
|---|---|---|---|---|---|
| Absence | 104 | 74 | 96 | 104 | 152 |
| Presence | 6 | 3 | 61 | 3 | 0 |

## 3.2 GAM-analysis

After using a backward selection five variables were left in the quasi-poisson distribution model while with the binomial distribution model two variables were left with significant results (Table 4).

Analysing the partial response curves for the quasi-poisson model (see figure 3 and 4) shows a negative relationship for round goby and distance to shipping traffic and salinity. Round goby has a positive relationship to depth and wave exposure. For slope there is first a negative relationship, and then a positive.

The binomial model (see figure 5) shows a positive relationship for round goby to distance to traffic and wave exposure.

Table 4. *The variables left after backwards-selection with significant result and the $D^2$ for the two final models (quasi-poisson and binomial distribution)*

| **Distribution** | **Significant variables** | **P-value** | **$D^2$** |
|---|---|---|---|
| Quasi-poisson | Distance to shipping traffic | 2e-16 | 83.4% |
| | Salinity | 2e-16 | |
| | Slope | 2.06e-10 | |
| | Depth | 2e-16 | |
| | Wave exposure | 2e-16 | |
| Binomial | Distance to shipping traffic | 8.63e-11 | 29.3% |
| | Wave exposure | 2.18e-07 | |

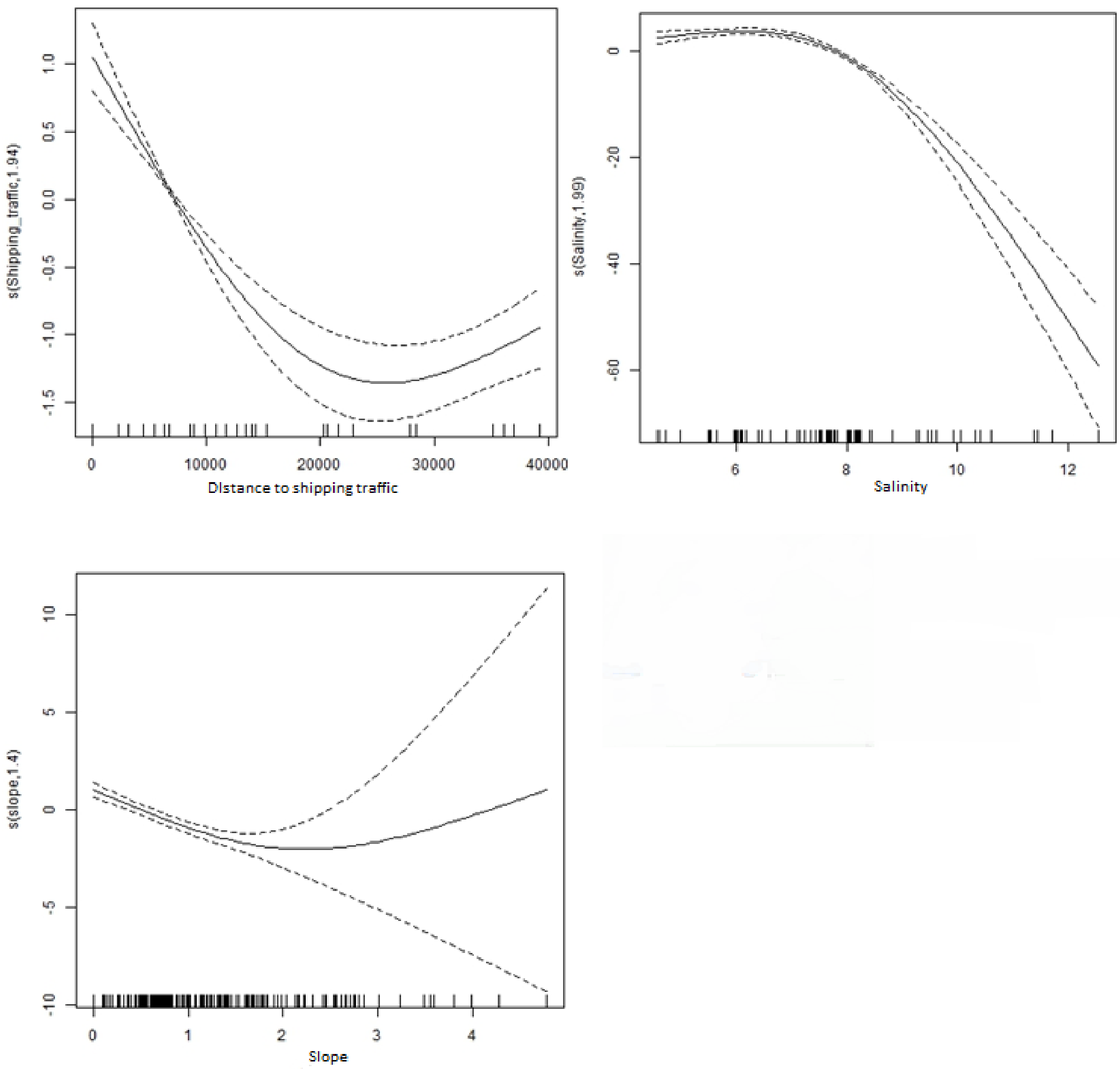


**Figure 3** *The partial response of round gobies to distance to shipping traffic (m), salinity (psu) and slope (%)  from the quasi-poisson model. The x-axis shows the range of the environmental variable. All graphs show the partial effects of each predictor on the cpues. Values above 0 on the y-axis indicate a positive effect of the predictor on the cpues. The black lines in the bottom of the figure shows the distribution of sampling points.*

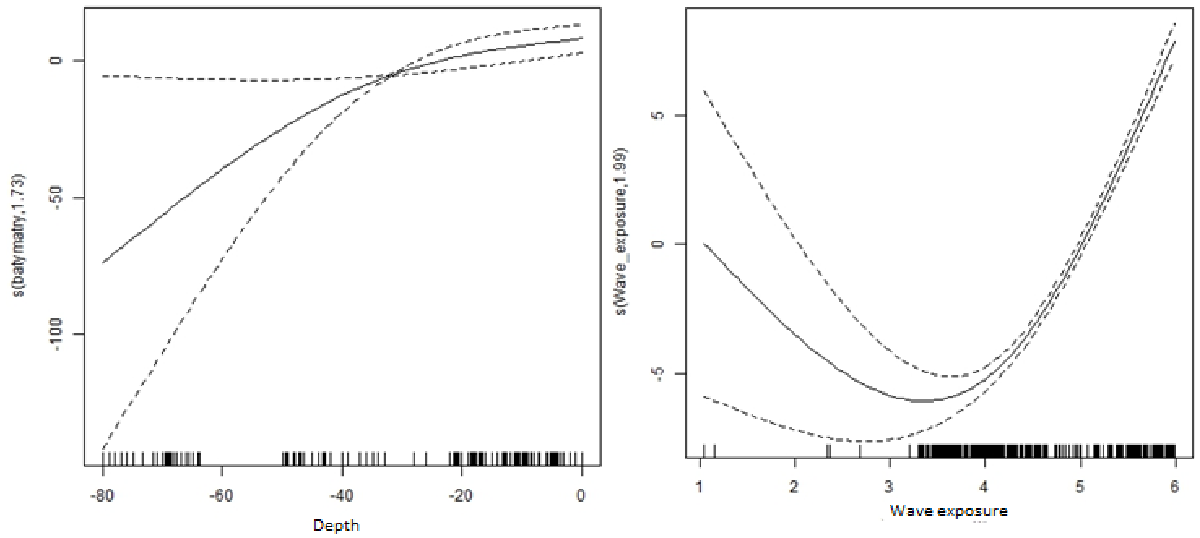


**Figure 4** *The partial response of round gobies to depth (m) and wave exposure (log m*$^2$*) in the quasi-poisson model. The x-axis shows the range of the environmental variable. All graphs show the partial effects of each predictor on the cpues. Values above 0 on the y-axis indicate a positive effect of the predictor on the cpues. The black lines in the bottom of the figure shows the distribution of sampling points*

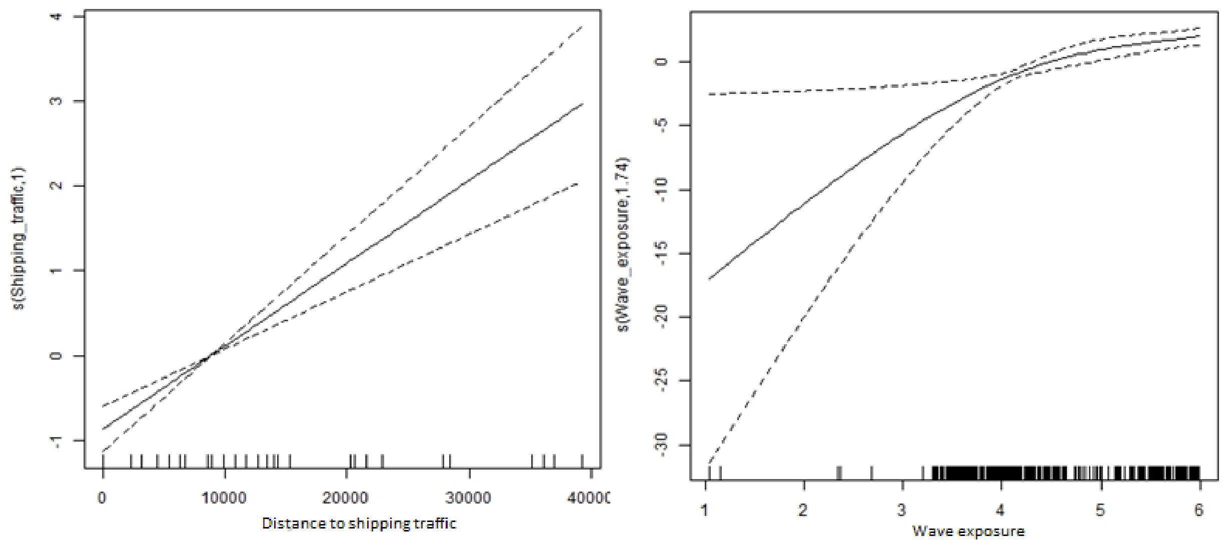


**Figure 5** *The partial response of round goby to distance to shipping traffic (m) and wave exposure (m*$^2$*) in the binomial model. The x-axis shows the range of the environmental variable. All graphs show the partial effects of each predictor on the cpues. Values above 0 on the y-axis indicate a positive effect of the predictor on the cpues The black lines in the bottom of the figure shows the distribution of sampling points.*

## 3.3 Predicted occurrence

In the quasi-poisson model distance to the shipping traffic shows a positive relationship with round goby abundance up to 9 000 meters, and values above that gives a negative relationship with the quasi-poisson distribution (see figure 3). Salinity has a weak positive relationship up to 8 psu, and above that value there is a negative relationship (see figure 3). Slope has a positive relationship to about 1%, and values above show a negative relationship (see figure 4). Depth has a negative relationship for deeper water and then a weak positive relationship for shallower water. Goby abundance shows a negative relationship with wave exposure up to 5 (100 000 $m^2$/s), above that value there is a positive relationship (see figure 4).

For the binomial distribution distance to shipping traffic shows a positive relationship from about 9000 meters, and for values below that there is a negative relationship (see figure 5). Values below ca 4.5 (31632 $m^2$/s) for the wave exposure shows a negative relationship while values over 4.5 shows a weak positive relationship (see figure 5).

Maps over predicted occurrence for round goby in the Baltic Sea based on the visual analysis of the partial response can be seen in figure 6 and 7. For both distribution models presence was found where the model predicts no occurrence. For the quasi-poisson the predicted occurrence is close to shore and in fewer areas compared to the binomial distribution where presence is predicted also in large offshore areas.

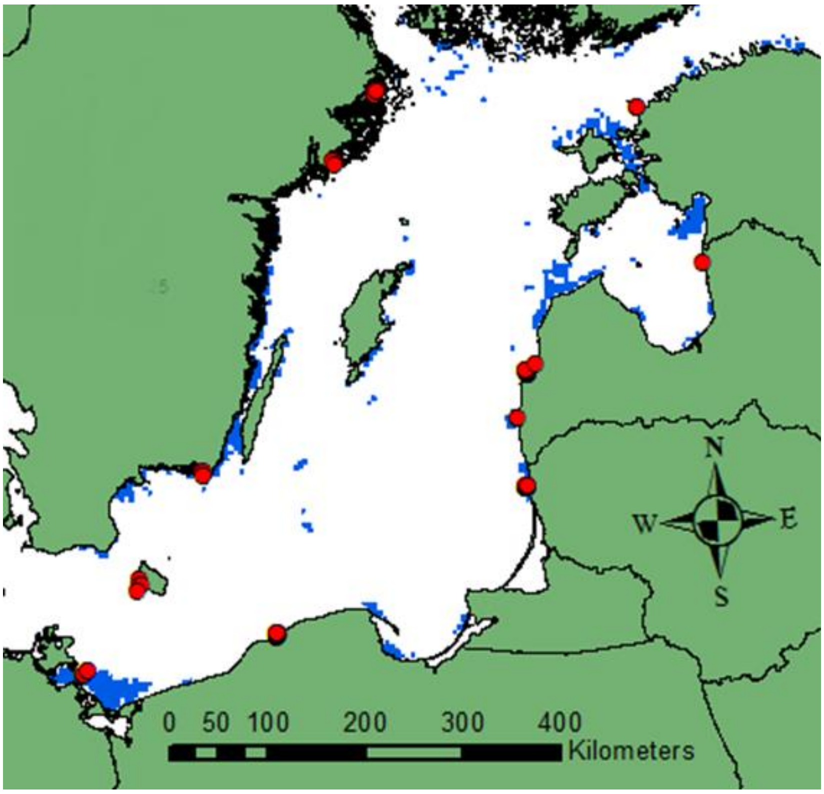

**Figure 6** *The predicted occurrence (in blue) using the quasi-poisson distribution of round goby in the central and southern Baltic Sea, red dots showing where there is presence in the monitoring-data used*

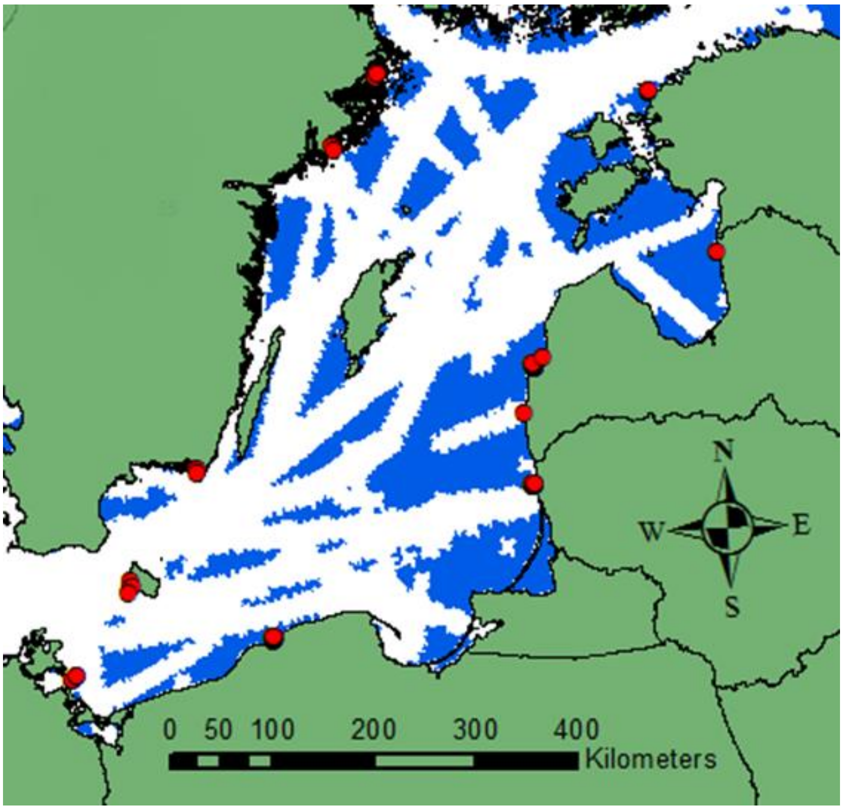


**Figure 7** *The predicted occurrence (in blue) using the binomial distribution of Round goby in the central and southern Baltic Sea, red dots showing where there is presence in the monitoring-data used.*

# 4 Discussion

The total deviance explained for the round goby were higher when using the quasi-poisson model (83.4%) than with the binomial model (29.3%). The results from the binomial model are excluded from further discussion because of the low deviance explained and the fact that the binomial map shows no predicted occurrence in the Gulf of Gdansk where the round goby first was introduced in the Baltic Sea.

According to this study the occurrence of round goby is closely related to shipping traffic, with no probable occurrence beyond a distance of 9 000 meters. The results comprises with earlier predictions, where the round goby is believed to have been transported with ballast water from its native environment (Kornis *et al.*, 2012). As the fish is further introduced in the Baltic Sea the relationship between these two factors could differ, if closeness to shipping traffic has the sole explanation that the round goby have been transported with ships. Earlier research of the round goby shows that the fish normally is sedentary (Björklund & Almqvist, 2009), however, some individuals migrate long distances and colonize new areas (Kornis *et al.*, 2012). With time the fish could therefore become less dependent on distance to shipping traffic and more dependent on other variables as it spreads further.

The relationship between round goby abundance and salinity correlates well with hitherto known presence of round goby, restricted to brackish and fresh water (the Black Sea and St. Lawrence River among other), avoiding areas with high salinity. In an experiment where the round goby was placed in water with a salinity of 30 psu, all the specimens died after 48 hours (Ellis & Macisaac, 2009). It would be interesting to follow the round goby in the Baltic Sea and their reaction to the increase and decrease of salinity when reaching further north and south as it so far has not colonized marine water.

In this study the round goby prefers shallow areas. In the review of round goby and its invasion in non-native areas the same relationship are given, where the round goby avoids deeper areas (Kornis *et al.*, 2012). However, there is also a study where there was a larger amount of round goby found in the deeper areas compared to the shallow (Cooper *et al.,* 2009). This could indicate that the relationship between round goby and depth is rather explained with another environmental variable that in most cases correlates with depth.

As for the slope, the round goby prefers a low percentage according to the quasi-poisson model. In a publication by Kornis and Vander Zanden (Kornis & Vander Zanden, 2010) the round goby has a negative relationship to an increase of slope and the results in this study are therefore supported by earlier work.

There was a positive relationship with wave exposure for occurrence from about 100 000 $m^2/s$, which is classified in table 2 as moderately exposed. The round goby should therefore avoid sheltered and very sheltered areas. This result is different than earlier predictions, where the round goby have been shown to spawn in shallow and protected areas along the Swedish coast (Florin & Karlsson, 2011). The relationship to wave exposure produced in this study could be a result of the limited number of monitoring data at low ranges of wave exposure, with few stations in sheltered and very sheltered areas compared to the exposed and very exposed areas.

The bottom substrate showed no significance in the modelling and was therefore excluded. However, as seen in table 3 there is a substantial amount of presence in sand compared to the other categories. The conclusion could be drawn that there is a relationship to bottom substrate and in particular a positive relationship to sand. In Lake Ontario the round goby preferred hard bottom substrate where it prefers to spawn, however areas without such substrate have not proven immune to invasion of round goby (Young *et al.*, 2010). The possibility for the round goby to spawn in multiple bottom substrate could be a contributing ability to its invasive capacities. Based on the results in this study, sand might be the favoured bottom substrate. However as the round goby continues to spread in the Baltic Sea, a larger abundance could be found in hard bottom substrate.

As round goby is an invasive fish in the Baltic Sea and still competing in the ecological environment of the Baltic Sea, it could be so that it have not been able to fully spread over the presumed preferred habitat. If this is the case, the fish could show another relationship to the environmental variables used in this study and become dependent on other environmental variables in the future.

The restricted range for data used in the model is an issue for all the environmental variables in this study (table 2). Even though most of the partial responses given with the quasi-poisson are correlating with earlier predictions, the total range of the environmental variables have to be used to see what possible preference the round goby (and other fish) has (Jackson *et al.*, 2001). Earlier results, in this case the previous predictions of environmental preferences, can always be questioned and to be able to do that the complete range has to be used.

The predicted occurrence does not cover all the locations where presence have been found of round goby. The possibility of continued spread in the Baltic Sea could therefore be larger than the predicted occurrence shown in blue in figure 6.

The data on the round goby was neither collected randomly nor systematically and there is a risk of biased results since round goby may well be found in habitats not represented in this dataset. Different monitoring methods were used in the 7 countries represented in this study. Time for monitoring varied from May to October. The effort may therefore not be equal for all monitoring. A future recommendation is to use the same method during the same time of year for all the data to have the same CPUE. Such a thing may not be a realistic improvement because of the cost of both time and money, but would be needed to create a more reliable model. An alternative to this is to use a more advanced method than presented in this study to recalculate different fishing to the same effort. I chose to analyse the data as abundance and did not account for the possibility that there were biases since the round goby may have been present but not detected at a point. With the amount of stations where no presences have been found, there is a risk of false absence. A possible solution could be fishing more than once in each location. Another distribution that could have been used for this dataset is zero inflated poisson, which allows an excess of zeros, i.e. absence (Lambert, 1992).

Using rasters from ArcMap to extract variables could create biased data. A more reliable analysis would be possible with values measured directly during monitoring. When using the amount of locations in this study there is a possibility of error when extracting from ArcMap because of the low capacity of the computer used. The different raster does also have different resolutions, creating a more precise value extract for some. This could affect the modelling, giving the more precise raster a stronger significance when there are more cells and therefore more precise value extraction.

In the future it would be interesting to look at the relationship between round goby and density of shipping traffic and not just distance to shipping traffic. If the round goby's presence is due to transport with ballast water as is strongly suggested in this study, there could be a possible relationship to the amount of ships. Temperature should also be included, as this could be an explanatory variable.

In conclusion the round goby prefers areas close to shipping traffic, with a low percentage in slope, shallow waters, moderately exposed areas and above for wave exposure, with a salinity up to 8 psu. The strong relationship with distance to shipping traffic supports the assumption that the round goby was transported here with ballast water. The results of this study shows that modelling using variable-extraction from a pre-made layer is a viable option, creating an opportunity to research more species in less time and with smaller costs than when measuring during monitoring. And as the round goby proofs to be versatile in its habitat preference with predicted occurrence in areas where it yet is to spread further work has to be done to hinder spreading of the fish.

## 4.1 Acknowledgment

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