# Assessing bottlenecks within the lifecycle of Atlantic herring encountered within the Wadden Sea


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swimway wadden sea

**Introduction:**

Due to the recent decline in many fish populations within the Wadden Sea, Danish; Dutch and German fish experts have proposed that changes need to be made to reverse current trends in fish diminution. As a result, conservation objectives for fish (named the Trilateral Fish Targets) were developed by project Swimway; which are aimed at preserving or increasing the suitability of the Wadden Sea area for different species of fish. However, at the basis of successful management, knowledge is required on the exact lifecycle of the species in question. Lots of information is already present and available due to years of research conducted by a plethora of researchers and specialists, though it is often scattered online. During my graduation project of my bachelor course I conducted online literature research on both the lifecycle of Atlantic Herring within the Wadden Sea area and potential bottlenecks encountered within, with the objective to funnel the bulk of information into one singular source. Since Atlantic Herring is the flagship species of 'Pelagic marine juvenile species', which is one of five Swimway categories based on lifestyle and behavior, this information may prove valuable to the Swimway Program and its objectives.

**Lifecycle (fig 1):**

**1.** Of the four main spawning stocks in the North Sea area, only the Banks stock and the Downs stock utilize the Wadden Sea during their lifecycle (Dickey-Collas et al., 2010; Herdson & Priede, 2010). Herring spawning in the North Sea begins in September in the North, seizing in the South at the end of January. The timing of spawning is fixed, occurring at the same time every year (ICES, 2015; Payne et al., 2009; Ruzzante et al., 2006; Sinclair & Power, 2015). After hatching, Downs and Banks herring larvae passively drift towards the southern North Sea, including the Wadden Sea, by means of currents created by winds (A) and the North Atlantic Oscillation (NAO). **2.** After herring larvae reach the nurseries during Spring, they take advantage of plankton blooms which commonly appear in coastal waters during this part of the year. Research has shown that seasonal egg and larval production is often mistimed with periods of favorable survival conditions, indicating that it is unlikely that autumn-spawning herring can avoid unfavorable conditions by delaying their spawning time or by spawning on more northern located grounds because of limitations in daylength to larval growth and survival (Hufnagl & Peck, 2011; Secor, 2007). This results in something called the match-mismatch theory in which herring has fixed spawning periods while the timing of phytoplankton blooms shows yearly variation, resulting in either good or bad yearly population strength (Sinclair & Tramblay, 1984). **3.** After reaching adulthood, herring move into the deeper central North Sea to feed. While all herring populations share these feeding grounds, the southern originating populations do not trek up as far north as the northern populations do (Corten, 2001a). **4.** When spawning occurs between September and January, inexperienced herring will follow older experienced herring to their spawning ground, to which they will return for spawning in the upcoming years. Herring spawning on the Banks and Downs stocks will continue this cycle in the upcoming years (Gulf of Maine Research Institute, n.d.; Clausen, 2007).

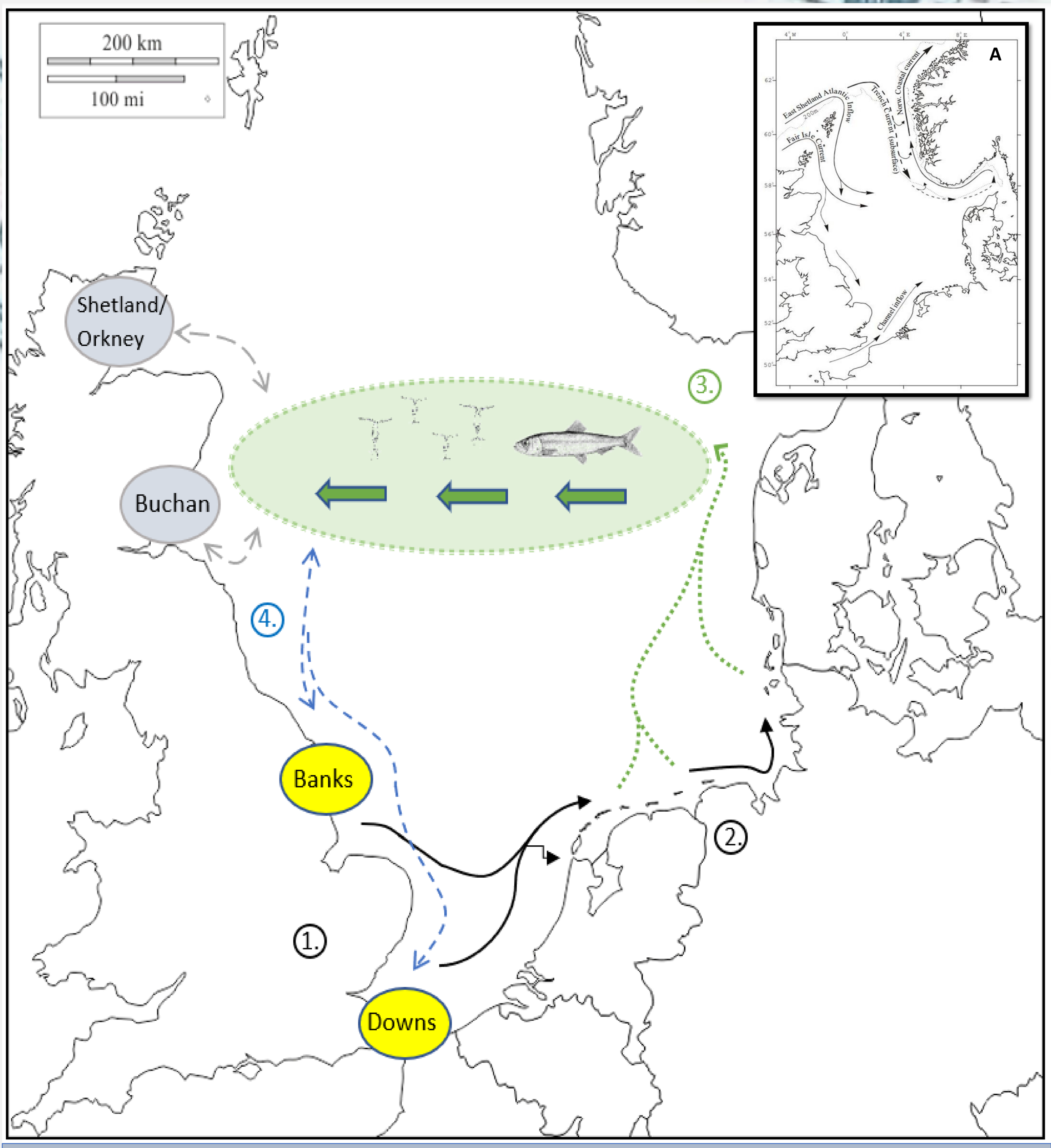


*Figure 1*: An overview of the triangular lifecycle of Atlantic herring, with empathis on the Banks and Downs stocks (yellow).

**Temperature increase & changes in NAO:**

It is expected that climate change will have pronounced effects on the distribution and abundance of fish through its influence on recruitment (Rijnsdorp et al., 2009). Even Though larval biomass is often higher during warmer years, larval mortality also increases with temperature often resulting in weak year classes. Some research does indicate a direct effect of temperature in which an increase in temperature renders warmer shallow areas unsuitable to herring, mostly through increased metabolic costs (Corten, 2013; Dickey-Collas et al., 2010; Fässler et al., 2011; Gröger et al., 2009; Hufnagl & Peck, 2011). However, other research indicates an indirect effect in which rising temperature is responsible for the exceedance of the physiological tolerance of main herring food item *C. finmarchicus* within the Wadden Sea (Akimova et al., 2016; Alvarez-Fernandez et al., 2012; Möllmann et al., 2008; Payne et al., 2013; Rijnsdorp et al., 2009) (fig 2). In the period between 1988±1990, a northern distribution of adult herring was not only linked with high water temperatures but also with low abundances of copepod *C. finmarchicus* (Corten, 2000; Corten, 2001b; Rijnsdorp et al., 2009). Expected future increases in temperature range from an 0.5°C up to 5.8°C increase in North Atlantic sea-surface temperatures over the next decade, of which shallow areas are affected the most (Edwards et al., 2006; Peperzak, 2003; Pörtner & Knust, 2007; Sims et al., 2004). The warming of the North Sea area also has the potential to accelerate water mass stratification, resulting in earlier plankton blooms. This might negatively affect herring recruitment though the match-mismatch theory (Rijnsdorp et al., 2009; Sinclair & Tramblay, 1984). Though temperature increase is expected to be a driving factor in many of these scenarios, it must be noted that yearly variations in recruitment are often a result of both global warming and the current NAO mode (Reid & Edwards, 2001; Weijerman et al., 2005).

Rather than climatic changes showing a progressive trend, changes in NAO-index are not necessarily continuous, often forming 'clusters' of unusually high or low temperature intervals (Rafferty, 2011; Reid & Edwards, 2001). Many researchers concluded that reduced larval survival during different time periods were caused by either unusual hydrological conditions or by temperature changes (Gröger et al., 2009; Kellnreitner, 2012; Rijke Waddenzee, 2015; Payne et al., 2009). Some past changes in pelagic fish stocks in the North Sea (including herring) could be explained by a reduced inflow of Atlantic water and changes to the circulation of the North Sea area. Specific periods of exceptionally long and high NAO-index, which resulted in long timespans of above average sea water temperature, are expected to be a direct consequence of global warming (Edwards et al., 2002; Reid & Edwards, 2001).

While changing salinity was also researched as a potential bottleneck, salinity has been stable throughout the years (besides the Great Salinity Anomaly in 1960) and yearly changes did not indicate imminent danger towards herring (Gulf of Maine Research Institute, n.d.; Reid et al., 1999).

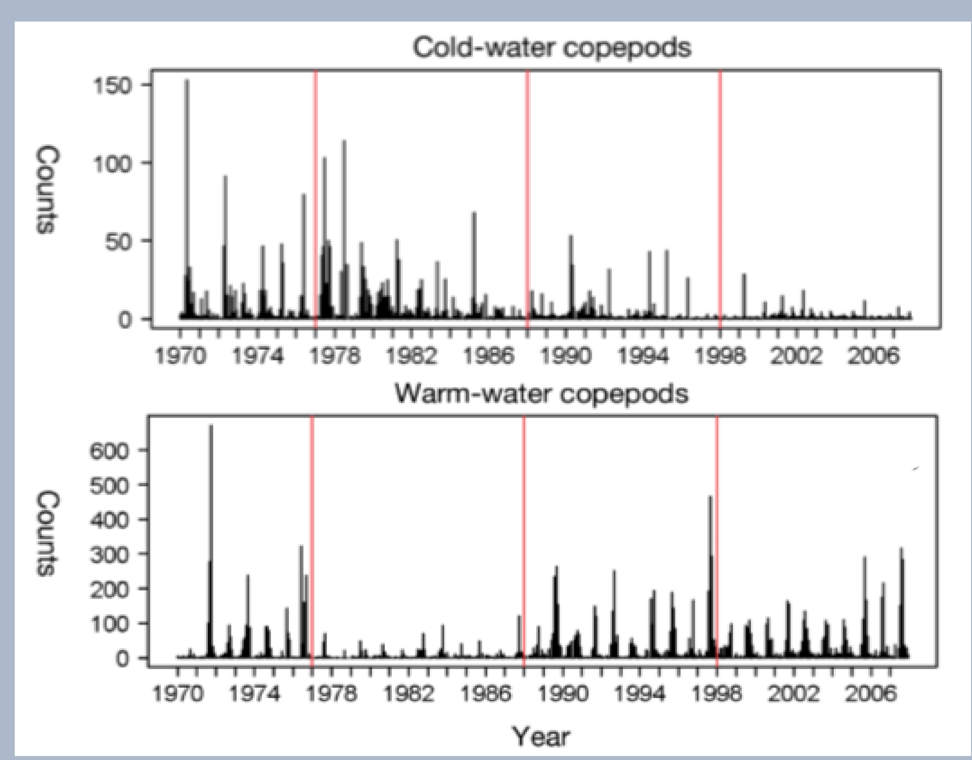


*Figure 2*: Yearly variations in zooplankton counts within the central North Sea, dividend in cold-water and warm-water species. Data presets an overall decrease in cold-water species as a result of high NAO-index, showing the effect of changes in sea surface temperature on plankton distribution. Zooplankton counts are mean number of individuals per sample (Alvarez-Fernandez et al., 2012).

**Fisheries and other human activities:**

Herring plays a key economic role with ~0.3 to 0.4 million tons landed yearly between 2007 to 2012 (Alvarez-Fernandez, 2015). Fisheries have seen, and been part of, long and short-term fluctuations within the herring stock over the years. There have been times in which the herring stock size thrived and periods in which the stock size came to a dangerous low (Corten, 2001b). in the 1950's till the 1970's there was a severe overexploitation of herring and it is estimated that the spawning stock biomass dropped from around 4,5 million tonnes in the late 1940's to lows of below 100000 tonnes in the late 1970's (ICES, 2016) (fig 3). This stock collapse was caused by heavy fishing pressure within the North Sea after the introduction of new fishing techniques including purse seine fishing (Bjørndal, 1989; Corten, 2013; Herdson & Priede, 2010; Rijke Waddenzee, 2015). Due to multiple crashes in herring stocks, total allowed catches (TAC's) where implemented to regulate the total amount of herring caught. To further prevent future stock collapses, herring stocks are consistently monitored and TAC's are changed on an annual basis (ICES, n.d.). Besides these measures, the spawning grounds of herring (like the gravel beds in the English Channel) are also closed to fisheries during spawning season (Overzee & Rijnsdorp, 2015). Current estimates of the herring stock suggest that the stock is close to its pre-collapse state and that only about 10% of the total herring stock is being exploited (Herdson, & Priede, 2010; Rijke Waddenzee, 2015) (fig 3). As a result, fishing pressure is not the threat it used to be and does not pose direct danger to the survival of herring stocks as it did in the generation prior.

Other human activities encountered by juvenile herring consist of oil exploitation, construction (and use) of wind turbines, military activity, dredging and men-induced eutrophication. Of the first two activities, sources indicate that the effect on herring is neglectable or even absent, often due to mitigating measures taken (Carpenter, 2018; Petersen & Malm, 2006). However, military activity and dredging are common in the Dutch part of the Wadden Sea and research on these activities in the area are lacking. Continuous shooting can contaminate the surrounding waters with lead and other heavy metals which are toxic to many marine animals (Polak-Juszczak, 2009). Nonetheless, due to the small scale of the military trainings in the Wadden Sea, the effect on the ecosystem is expected to be neglectable (Brenner et al., 2017). As for dredging, the Wadden Sea is an intertidal area in which turbidity is already high, which makes inhabitants naturally resistant to turbid waters, at least temporally. Additional research is required on these two activities within the Wadden Sea as dredging might release trapped heavy metals, introduced by military activity, or might increase the threat of eutrophication in a warmer future perspective. However, both activities are a lesser priority compared with global warming. Eutrophication, which is a direct result of Anthropogenic sources including agricultural wastewater, should also be monitored on a regular basis since current chlorophyll levels in the Northern Wadden Sea are a least 50% higher than the threshold agreed on in the Water Framework Directive (Van Beusekom et al., 2017). While eutrophication does not pose a direct threat like temperature increase does, partly due to countermeasures taken in 1970 to limit nutrient input from rivers, it might pose problems when combined with future temperature increases. Currently the utilization of monitoring stations within the Wadden Sea vary on a yearly basis (Van Beusekom et al., 2017).

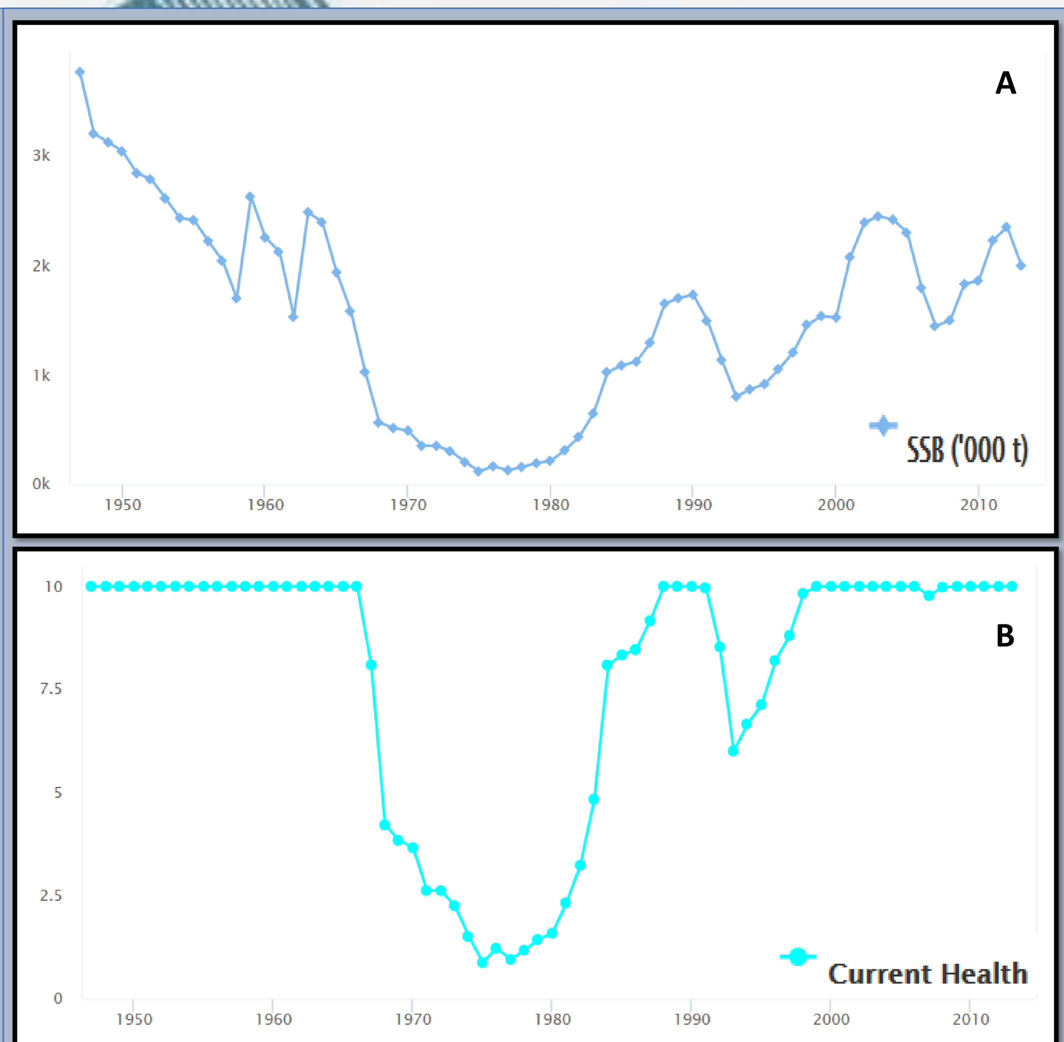


*Figure 3*: Spawning Stock Biomass (A), which represents the amount of adult Atlantic herring which drive the recruitment in the North Sea area, and the overall health of herring of all age-classes (B) (SFP, 2019). Both dropped significantly during the late 1900's due to the introduction of new fishing techniques and high fishing pressure. Current management achieved sustainable fisheries in the 2000's.

**Recommendations:**

Since bottlenecks discovered in the lifecycle of herring are primarily driven by climate change, the problem is mostly out of Swimway's hands. Right now it is mostly speculation on the future temperature increase since models show varying results which are often location specific. While it might be near impossible to reverse the warming of the North Sea, especially since the warming and cooling of seas and oceans are a natural phenomenon, it will be possible to reduce other stressors which might amplify the impact of climate change on herring. military activity, dredging and eutrophication are stressors which potentially threaten the successful survival of juvenile herring in the Wadden Sea area. Close monitoring of eutrophication in the Wadden Sea is the backbone of keeping the nutrient input in the area on a stable level. For the most optimal results, all monitoring stations should be active each year. This way, critical nutrient levels can quickly be acted on when they do occur. In addition, more research should be conducted on the combined effects of eutrophication, dredging and military activity in the area. With this acquired knowledge, Swimway will have a better chance of successfully implementing the targets to maintain or improve: '*robust and viable populations of estuarine resident fish species within the Wadden Sea*' and '*the nursery function of the Wadden Sea and estuaries*' for pelagic juvenile species, like herring. For the other Swimway species, a similar approach can be used to define bottlenecks and knowledge gaps in the lifecycle of these species. While the temperature increases in the Wadden Sea probably affects all fish species utilizing the area (Dulvy et al., 2008), other bottlenecks on herring might have little or no effect on the other Swimway species. On the other hand, found bottlenecks might affected other Swimway species even more. Final recommendations go towards performing similar (successive) research on other Swimway species, to aid the Swimway Action Programme in achieving the Trilateral Fish Targets in the Wadden Sea.