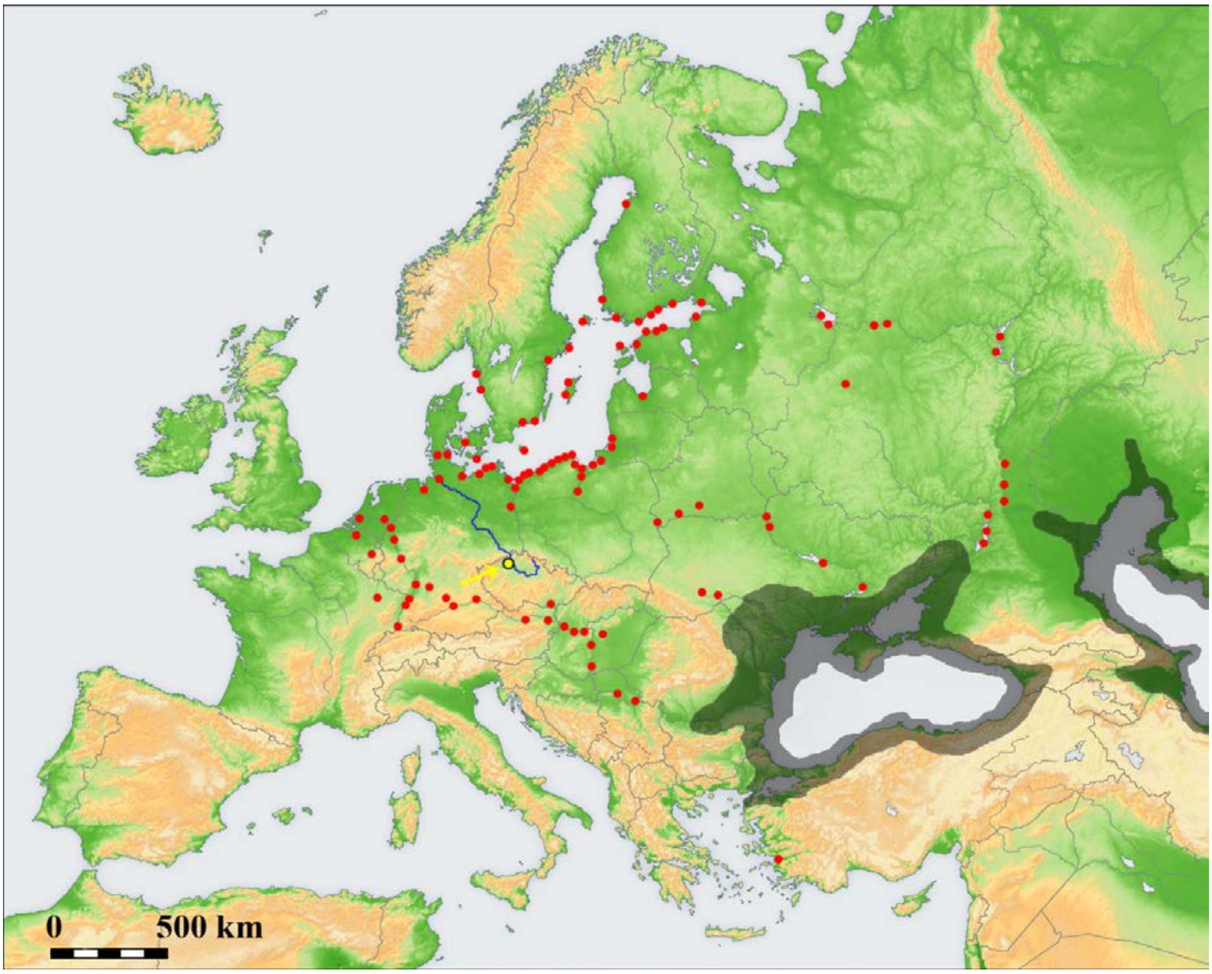
Background paper on the biology of the round gobies

The invasive round goby

The round goby's (*Neogobius melanostomus*) natural habitat is the Caspian and Black Sea, Sea of Azov and Mamara as well as the surrounding river systems. The surprise was therefore great when specimens of round gobies started to be found in the Baltic Sea in Northern Europe and in the Great Lakes in North America in the beginning of the 1990s. Today it is believed that this remarkable dispersal of round gobies was facilitated by cargo ship's use of ballast water. Large cargo ships transport substantial amounts of water in ballast tanks to improve their stability and balance. The filling of ballast water tanks with water containing round gobies, and the subsequent emptying of the same ballast tanks in the US or the Baltic Sea, represent the most plausible explanation of how these fish got relocated. In central Europe, where round gobies are also found, the dispersal is expected to have happened through rivers and canals. A recent mapping by Buric and colleagues (2015) thus found round gobies to have spread into many freshwater canals and rivers not just in both Europe and Russia.



Map by Buric and colleagues (2015). Grey area represent the round goby's indigenous habitat, and the red dots identified specimens exemplifying its ongoing expansion and invasive nature.

A similar invasiveness has also been observed in the United States where round gobies can now be observed in all the Great Lakes and four inland rivers of Ontario and Michigan as well as in a Shipping Canal to the Mississippi River.

The problem with invasive round gobies

The round goby's dispersal to areas where it is non-indigenous is a concern to countries, as they pose a threat to local wildlife, ecosystems and the people who depend on the ecosystems for income through e.g. fisheries. Some of these concerns are related to the round goby's consumption of native species. In the Baltic Sea changes in the biomass and density of indigenous fish have for example already been documented, and in the Great Lakes recruitment of lake trout and lake sturgeon have been affected as the round goby feed of their eggs. Presently many countries are therefore concerned how it will disperse in the coming years and what the long term impact on the ecosystems will be. This knowledge is necessary for the development of management plans aiming at addressing the potential negative effects of this alien fish invasion.

Biology

The round goby is a small fish, often no more than 18 cm. Round gobies are characterised by raised eyes, thick lips and potentially a number of black dots on the side of the body. It can live up to four years (in the wild found until 6 years old), and reach maturity at around 2 -3 years for females and 4 years for males.

The round goby is sexually isomorphic, meaning that the sexes cannot be distinguished only by appearance. Usually however, the male is larger than the female at the same age. The females lay their eggs multiple times between April and August, with hatching taking up to 18 days. The number of eggs produced varies with body weight of the female and is about 90 to 2200 eggs, with an average around 645 eggs.

The mating behaviour of round gobies is a rather strange story. Female gobies, like most other fish, release their unfertilized eggs into the water. However the male gobies, which must fertilize the eggs, have two very different strategies to achieve reproductive success. In the first strategy, the male fertilize the eggs by releasing their sperm over the them, and then decides to take care of the nest and eggs. These males are generally very dark in their colour and with large heads. In contrast to this strategy, the other type of males, which are less dark and smaller, adopt a "sneaking" tactic, where they wait for a couple to mate and then shortly after sweep in and ejaculate a large amount of sperm over the eggs, thus fertilizing them. In this tactic, the males does not stick around and protect the nest.

Habitat preferences

The round goby lives close to the bottom in shallow waters, where they appear to prefer depths less than 10m, though they have been found down to 90 meters also Their diet is broad, including small crustaceans, marine worms, fish eggs, larvae and molluscs. Their predators vary according to the region, in the Baltic Sea for example, Great Cormorant is the main predator together with cod and perch, while in North America several fishes and waterfowls act as predators. Round goby can be found on both rocky and sandy bottoms, with rocks potentially acting as hiding places during the night where some predators are more active. Round gobies are found in a wide range of salinities (the amount of salt dissolved in water), from zero (in fresh water) to 22 parts per thousand (in the Black Sea). This provide round gobies with the natural ability to conform to many different salinities which they might encounter as a consequence of a potential relocation.

Physiology 1 – the need for oxygen

Fish are vertebrates and thus eukaryotes, which have **cells** containing the same organelles as humans. This means that they for example carry out aerobic respiration in their mitochondria in order to produce energy in the form of the energy storing molecule adenosine triphosphate (**ATP**). Given that this is an **aerobic process**, fish like humans, must use oxygen (**O_2**) for this process, which must be obtained from their surroundings. Additionally fish must (obviously) also get rid of carbon dioxide (CO_2) which is the byproduct of aerobic respiration. Although we live in different environments (i.e. water versus air), the cellular processes, which support the metabolism in fish and thus maintain their **physiological** demands, are therefore in many ways identical to those of humans.

Like humans, fish **must increase their oxygen consumption** in order **to increase energy production** to support activities related to e.g. catch of prey, predator avoidance or growth. It is therefore not surprising that many studies has linked the individual fitness and growth potential of fish populations to their oxygen transport. The degree to which a fish is able to increase its oxygen consumption is thus a good indicator for its ability to support energy demanding processes and hence cope with any internal or external factor affecting its energy demands. How well a fish does this is reflected in its so-called "aerobic scope" (AS). To find the aerobic scope of a fish two measurements of oxygen consumption must be carried out 1) where the fish is at rest and not digesting, and 2) where the fish is as active as possible. The difference in the rate of oxygen consumption between these two activity states is the aerobic scope (AS). In fish research these measurements are called:

1) The Standard Metabolic Rate (SMR) = the oxygen consumption where the fish is resting and not digesting
2) The Maximum Metabolic Rate (MMR) = the rate of oxygen consumption where the fish is as active as possible

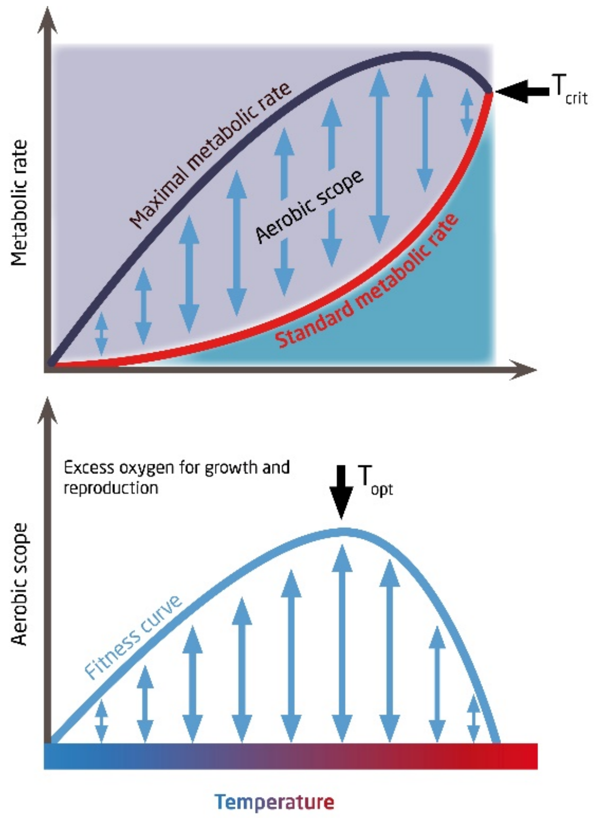
The relation between these measurements can be described by the equation:

$$\text{Aerobic scope (AS)} = \text{MMR} – \text{SMR}$$

In fish, both SMR and MMR – and hence AS - are affected by temperature and salinity (an example with effects of increasing temperature on AS can be seen in Figure 1). Notably, with increasing temperatures MMR increases at a faster rate compared to SMR until a maximum level is reached for

MMR where it starts to decrease. MMR drops in the end because the cardio-respiratory system starts to fails at these high temperatures. In figure 1 the temperature shown as "T_{crit}", hereby indicates that the fish is reaching a critical temperature above which, it will not be able to catch prey, grow or avoid predators. Additionally the temperature shown as "T_{opt}" indicates the temperature at which, the fish has the highest levels of oxygen available for the same things.

Figure 1.Aerobic scope and metabolic rate in relation to temperature. Modified from Verbek et al, 2016.



Physiology 2 – coping with salinity

Fish like humans have tissue and cells which need to have the right concentrations of different ions and water for them to function properly. In other words, the fish need to maintain internal homeostasis. Through evolution all organisms (including fish) have been adapted to cope with particular environments. In aquatic environments, organisms must cope with different levels of salts, and their physiology is therefore fine-tuned to the ranges of salinity, which they normally encounter.

Many organisms including fish are however faced with the need to have a slightly different concentration of ions in e.g. their blood and tissue than the surrounding environment. Due to osmosis, such ion gradients will only be maintained if an active regulation takes place in the exposed tissue's permeable cells. In fish this tissue is mainly the gills and the gut. Especially the gills are so permeable that not only oxygen and carbon dioxide can across its thin membrane but also sodium and chloride. To keep the internal concentrations under control **osmoregulation** is therefore required.

Osmoregulation is the **active process** to control differences of osmotic pressure between internal and external fluids by keeping, obtaining or releasing water, ions and other solutes. The process is carried out by specific pumps in the cell membrane. Marine fish are **hypotonic** to salt water, causing them to passively loose water and gain ions over their gills and gut, while freshwater fish, being **hypertonic** to their environment, gain water and loose ions. To counteract this, fish must use energy in the form of ATP to counteract the passive osmosis. So, in theory, this indicates that fish inhabiting salinity levels either above or below their internal salt concentrations will have to spend more ATP to maintain the internal homeostasis, than a fish living in water where the ambient salinity is closer to the internal concentrations of the fish's blood and tissue (table 1).

The link between fish, salinity and energy requirements

Fish	**Salinity in water**	**Effect on exposed tissue**	**Cellular requirement**	**ATP demand**	**Oxygen demand**	**SMR**	**AS**
A	Isoosmotic* to the internal environment of the fish	Constant water content in tissue	A bit of osmoregulation	Low ATP use	Low	Low	Unaffected
B	Much lower than the fish's internal concentrations	Absorb water from surrounding water	Substantial osmoregulation	High ATP use	High	High	Reduced
C	Much higher than the fish's internal concentrations	Loose water to surrounding	Substantial osmoregulation	High ATP use	High	High	Reduced

*Isoosmotic means that the salinity inside the fish is the same as the water around it.

Table 1: The effect of water of various salinities on fish. Each column demonstrates how e.g. a high salinity will increase the loss of water over the gills due to osmosis. To counteract this passive loss of water, substantial osmoregulation is required by the cells. This osmoregulation is an active process, and will thus demand a high use of ATP which again will only be available if the fish increase its aerobic metabolism, where oxygen is demanded. Finally as a consequence, the standard metabolic rate (SMR) will increase and thus reduce the aerobic scope (AS).

Most fish are adapted to cope with a narrow range of salinities, and they will die if exposed to salinities deviating much from their optimal salinity. Some species however very good at osmoregulating and can hence tolerate a wide range of salinities. One way to test the osmoregulating ability of fish, is therefore simple to perform an experiment with different salinities.

References

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