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Cardiorespiratory Function of Euryhaline Teleosts

Regulatory Mechanisms, Effects of Warming and Costs of Osmoregulation

Daniel Morgenroth Navas
Institutionen för biologi och miljövetenskap
Naturvetenskapliga fakulteten

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Abstract

Teleost fishes have colonized almost every aquatic habitat on earth and exhibit adaptations that allow them to thrive in environments with very diverse physico-chemical properties. One fundamental environmental variable in aquatic ecosystems is salinity, as most fish species are only able to tolerate a narrow range of salinities. Nevertheless, a small proportion of fish species are euryhaline, meaning that they can live in a wide range of salinities including freshwater and full strength seawater. While there is substantial knowledge about some aspects of the physiological mechanisms underlying euryhalinity, the cardiovascular mechanisms in different salinities have so far been surprisingly overlooked. Furthermore, human-induced climate change is severely increasing the frequency and magnitude of extreme weather events including draughts, floods and heatwaves, which may severely alter temperature and salinity conditions of many aquatic habitats. Thus, temperature and salinity are two environmental drivers that can interact and may have unexpected physiological consequences for fish, but this has so far received relatively limited attention. The aim of this thesis is to increase our knowledge on the cardiovascular adjustments and their regulatory mechanisms in euryhaline fishes at different salinities. I also examined the linkages between cardiorespiratory function across salinities and aerobic and growth performance, as well as the interacting effects of environmental warming on cardiovascular function.

Rainbow trout acclimated to seawater typically display stroke-volume mediated elevations in cardiac output and reduced dorsal aortic blood pressure. First, using *in vivo* recordings of cardiovascular function and pharmacological tools, I assessed the role of α-adrenergic control systems in eliciting these cardiovascular responses. I found that systemic vascular resistance was lower in seawater-acclimated rainbow trout partly explaining the arterial hypotension. Additionally, the reduced vascular resistance was partly due to a lowered α-adrenergic tone on the vasculature.

Marine fishes drink to compensate for the dehydrating effects of living in seawater. This is associated with elevated gastrointestinal blood flow likely to provide oxygen and transport water, ions and waste. In a second study, I tested whether gastric perfusion of a hyperosmotic fluid in freshwater elicits some of the cardiovascular changes observed in fish transitioning to seawater. Gastric perfusion resulted in stroke volume-mediated elevations in cardiac output, elevations in gastrointestinal blood flow and reduced vascular resistances. This suggests that intestinal osmo- or mechanoreceptors mediate in the cardiovascular responses observed in seawater.

Cardiovascular responses to warming may differ depending on the environmental salinity as increased water temperature exacerbates dehydration in seawater and fluid gain in freshwater. Rainbow trout in freshwater and seawater exposed to acute warming increased gastrointestinal blood flow as well as cardiac output via elevations in heart rate. Nevertheless, the increase in cardiac output and gastrointestinal blood flow in seawater-acclimated trout was larger. This suggests enhanced compensatory elevations in gastrointestinal water processing, requiring improved gastrointestinal oxygenation and convective transport of nutrients, water and ions. The larger elevations in cardiac output also suggest that scope for increasing cardiac output may be compromised at higher temperatures in seawater.

Optimization of gas exchange across the gills also increases the exchange of water and ions. Due to this, high-energy demand fishes can be hypothesized to have large costs of osmoregulation, which may be reduced in brackish water. Here I show that the yellowtail kingfish, an aerobically active pelagic species, acutely and long-term exposed to brackish water maintained metabolic rate and cardiac function similar to kingfish in seawater, although acclimation to brackish water was associated with cardiac remodeling. Growth performance was also unaffected by acclimation to different salinities.

Collectively, I show that α-adrenergic stimulation mediates some of the cardiovascular responses observed in trout at different salinities and that hyperosmotic fluid ingestion likely regulates cardiovascular function via internal gastrointestinal sensing mechanisms. Furthermore, the magnitude of the cardiovascular responses elicited by warming depend on the environmental salinity, reflecting the osmoregulatory role of the gastrointestinal tract. Finally, acute and long-term reductions in salinity had few cardiorespiratory effects on kingfish suggesting that this high-energy demand species has lower costs of osmoregulation than initially hypothesized.

Keywords: salinity, temperature, cardiac, vascular, gastrointestinal, acclimation, growth