Spatial ecology of lacustrine fishes: ecological effects and applied aspects

This thesis investigates aspects of the spatial ecology of lacustrine fishes, i.e. how movement patterns and activity may influence on lake ecosystem functioning and applied lake management issues. The first paper (paper I) explores changes in predator-prey interactions caused by partial migratory prey fish on top-predators foraging ecology. Specifically, it was tested whether partial seasonal migration of certain prey species within the overall prey community affected the foraging ecology of a top-predator (pike, Esox lucius). Partial-migratory prey fish leave the lake and over-winter in connected streams and therefore could cause a reduction in available prey biomass in the lake resulting in changes to the foraging ecology of resident predators, such as pike. These predator-prey interactions was examined in replicated freshwater lake systems, four with- and four without opportunity for prey migration. Specifically, predator foraging mode and prey community structure in lakes where cyprinid prey fish perform seasonal partial migrations into connected streams were compared with lakes with no migratory opportunities for prey fish. Results showed clear seasonal bottom-up effects of prey migration on foraging ecology of pike. Diet size-structure and species composition of predators in lakes exposed to migrating prey vary during the winter season compared to pike predators not experiencing fluctuating prey biomass. Furthermore, pike exposed to migrating prey experience a size-specific change in littoral versus pelagic origin of diet, and reduced somatic condition during the prey migration period. In conclusion, seasonal prey migrations have important implications for predator foraging ecology, and may cause seasonal shifts in the importance of their supporting energy pathways.

In the second paper (paper II) the overarching theme was again to explore the link between spatial fish ecology and potential ecosystem effects through an examination of how the feeding activity of bream (Abramis brama), an important benthivorous fish in many lakes, may affect lake ecosystems including functionality. A potential relationship between benthivorous bream activity behavior and their impact on water turbidity was investigated on a day-to-day basis under natural conditions. Benthivorous bream are highly specialized ecosystem engineers with their foraging behavior disturbing the lake sediment in search of food organisms. This foraging behavior has several potential effects on the ecosystem, i.e. it results in resuspension of sediment, increasing water turbidity, prevents the establishment of submerged macrophytes through mechanical stress, and may cause release of nutrients retained in the sediments back into the water column. Bream foraging behavior ultimately results in lower light penetration through the water column, loss of submerged macrophytes, decreases in zooplankton, and increases in phytoplankton in the lake. This study (the first full-scale under natural conditions) describes how bream activity influences lake turbidity on a day-to-day basis. A clear relationship between daily bream activity and water turbidity was found, particularly when water temperatures where relatively low (below 15°C). No clear relationship was found when water temperatures exceeded 15°C, likely due to effects being masked by the increased phytoplankton production during spring and summer. This finding adds an important seasonal dimension to the previous knowledge about the structuring role of benthivorous bream in lake systems, and implies that winter activity of benthivorous bream may play a role for maintaining lake ecosystems in a turbid state, e.g. by transferring nutrients from the benthic to pelagic realms, and potentially also by preventing important establishment of submerged macrophytes in the spring through shading or mechanical stress.

In the third paper (paper III), passive telemetry technology was used to describe long-term movement patterns of 1280 individually tagged adult benthivorous bream in a multi-lake drainage system during nine years. The movement pattern is best described as partial nomadism, where a part of the population are neither resident nor migratory but move between lakes in an unpredictable arrhythmic fashion, often with long residency in one lake before moving to the other lake. On average 15% of the tagged bream changed lake within the first year after tagging, but there was extensive variation in the amount of moving bream between years, from 0% to 37%. In total, 30% of the bream that changed lake returned to the lake of tagging after 1-3 years but the majority never returned. Notably, movements out of lakes were significantly more in direction of the neighboring lake than away from the sister-lake system, suggesting that at least direction was not random. This opens up for important questions regarding the mechanisms governing the patterns of nomadism. Further, since bream are important bioengineers, fluctuating densities of adult bream could cause instability in the ecological state of lakes.

The fourth and final paper (paper IV) focused on applied aspects of spatial ecology of lacustrine fish, i.e. how knowledge about seasonal movement patterns of cyprinid fishes can be used to improve current methods used to restore eutrophicated lakes. Specifically, the study explored how cyprinid fish removal from streams can be used as a tool in biomanipulation of lakes, i.e. as a supplement to the traditional in-lake fish removal. Cyprinid fish often perform seasonal partial migrations out of lakes and over-winter in streams. In Lake Segård a small, eutrophic, shallow lake, results of two consecutive years demonstrated that it was possible to annually remove up to 35% of the dominant cyprinid fish species via the stream. Further, it is argued that even higher amounts could be removed with a more targeted fishing effort, as up to 82% of the lake population moved into the streams during winter. These results indicate that fish removal from streams could be a supplementary tool in biomanipulation. Moreover, the method seems cost effective compared to other methods as seasonal migrating fish aggregate in fairly restricted areas within the stream and therefore are relatively easy to catch. When examining individual fish migration patterns in order to evaluate species- and length-specific variation in migration propensity, it was found that smaller planktivorous fish in general had a higher propensity to migrate compared to larger fish. Since large benthivorous fish, such as bream, do not participate in seasonal migration, fish removals from streams should be supplemented with in-lake removal methods in lake systems where benthivorous fish are the target group. As a rule of thumb, stream fishing seems most efficient when water temperatures are 2-6°C. Finally, prior to implementing fish removals from streams, it is argued that potential evolutionary consequences of the targeted removal of migratory phenotypes should be considered.

Combined, the results from this PhD thesis have provided new knowledge about spatial ecology of lacustrine fish in lakes,
as well as knowledge about other aspects of the biology of these fish. For instance, how seasonal migration of cyprinid prey fish can influence fitness of a top predator as well as the energy pathways between trophic levels in lakes. The fact that this is showed in a replicated full scale ecosystem design, suggests robust results and the patterns found are likely to apply to, e.g. terrestrial ecosystems. Furthermore, the studies in this thesis provide new information about behavior of adult benthivorous bream. Bream activity within a lake was showed to influence water turbidity, even during cold periods of the year. Thereby, an important seasonal dimension was added to how adult bream can play a structuring role in eutrophic lakes. Likewise, the findings of unpredictable nomadic movements of adult bream between lakes add new information about the biology of adult bream. Moreover, these arrhythmic movement patterns can challenge previous practises, i.e. where lakes are managed as isolated units. Finally, since movements of adult bream between lakes are likely to result in fluctuating densities within a given lake, the findings in this thesis introduces a new explanation to why shallow eutrophic lakes sometimes alternate abruptly between different trophic states. Eutrophication is an important threat to many freshwater systems, such as shallow lakes, and biomanipulation is an important tool to mitigate this problem. Prospectively, findings of biomanipulation in streams as a cost effective supplementary tool to traditional biomanipulation methods, can turn out to be valuable knowledge for future lake restoration project.