



*A House of Cards: Patterns of Aquatic Invertebrate Diversity in Agricultural Ditches*

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## Summary

Agricultural environments cover about a third of the earth's land area and contribute significantly to biodiversity, yet agricultural intensification is leading to a global decline in biodiversity with aquatic systems being the most at risk. The low-lying landscape of North Holland, The Netherlands contains an interlacing network of drainage ditches and its peatlands are remnants of a once vast system of floodplains and raised bogs, which can still support a range of aquatic invertebrates. However, these drainage ditches are subject to regular disturbances from the inlet of mineral rich river derived water, eutrophication, regular vegetation removal and sediment dredging, leading to a decline in the diversity of invertebrates and plants over recent decades. To prevent further biodiversity loss it is essential to identify the dominant environmental drivers and mechanisms underlying the distribution of aquatic invertebrates in this heavily impacted ecosystem.

This thesis seeks to elucidate how aquatic invertebrate communities are structured by environmental drivers in North Holland's agricultural drainage ditches. To this end the following questions were defined:

- What are the key environmental drivers determining aquatic invertebrate community composition in agricultural ditches?
- What are the mechanisms underlying the response of aquatic invertebrates to these environmental drivers?
- How can management practices be adjusted to improve ecological conditions in the agricultural ditches?

Peat degradation causes the accumulation of fine particles in the aquatic environment and can lead to the decline of submerged macrophytes, which provide necessary habitat for benthic invertebrates. Therefore in Chapter 2 the decadal (1985 – 2007) trends in benthic species richness were investigated in 29 peatland ditches by reviewing long-term monitoring data from the province of North Holland. Monitoring data were analysed in conjunction with a complementary field experiment, in which submerged artificial macrophytes, natural sediments and emergent bank vegetation were sampled in degraded peatland ditches, to determine patterns of macroinvertebrate habitat occupancy. The long-term monitoring data shows that chemical conditions in agricultural peat ditches have improved (slightly) over recent decades, yet the diversity of benthic invertebrates have declined, concomitant to a decline in submerged macrophyte diversity. The dependence of macroinvertebrates on macrophytes was reinforced by

our field experiment which revealed that invertebrate density was highest in submerged artificial plants and invertebrate species richness was highest in natural emergent vegetation. Conversely, degraded peat sediments supported extremely few invertebrates. Thus the degradation of peat predominantly had an indirect effect on benthic invertebrate diversity via the loss of essential macrophyte habitat.

As described above the availability of submerged macrophyte habitat is an important driver of aquatic invertebrate communities, yet eutrophication and peat degradation are leading to the decline of submerged vegetation. Emergent vegetation is able to persist in eutrophicated ditches, however vegetation removal is carried out annually and can reduce the availability of this habitat. Thus, in Chapter 3 we applied the landscape filtering approach to determine how the absence of emergent vegetation structured aquatic insect communities in peatland drainage ditches under different trophic conditions. To this end, aquatic insects were sampled in emergent vegetation stands in one mesotrophic and one eutrophic peatland. In addition to taxonomic responses, functional community composition was studied by assigning life-history strategies to insect species to determine the influence of vegetation structure and peatland type on taxonomic and functional community structure. The findings showed that ditches in the eutrophic peatland were dominated by insects adapted to abiotic extremes, while species with good dispersal abilities were strongly related to emergent vegetation cover. Our results indicate that while peatland type appeared to primarily determining the pool of species within each wetland, emergent vegetation acted as a secondary filter by structuring functional community composition within ditches.

The inlet of mineral rich, river derived water can alter abiotic conditions and is expected to influence drainage ditch communities. Yet, it is often impossible to disentangling, interconnected abiotic parameters in the field. The potential of benthic microbial composition to reveal environmental drivers of insect communities has not been explored. Thus, in Chapter 4 we investigated benthic microbial community composition in 25 peatland ditches by analysing phospholipid fatty acid (PLFA) profiles and investigate correlations with aquatic insects. Furthermore, we examined relationships between microbial and insect data alongside abiotic parameters, emergent and submerged vegetation. PLFA composition indicated the dominance of eukaryotic algae, cyanobacteria, sulphate reducing bacteria, (gram positive) anaerobic bacteria and gram negative bacteria in the microbial community. Moreover, ditches that were distinguished by their microbial communities differed significantly in insect composition, in particular Odonata, Trichoptera and *Chironomus* larvae. The main environmental factors underlying this pattern were the presence of submerged and emergent vegetation and concentrations of bicarbonate, sulphate and nutrients. These particular abiotic parameters are known to be associated with the inlet of

mineral rich river derived water. These findings demonstrated that the inlet of external mineral rich waters was negatively impacting ditch community composition.

The inlet of mineral rich waters is also expected to cause variability in abiotic conditions. Yet the importance of abiotic variability has not been investigated for invertebrate communities in Dutch drainage ditches. In Chapter 5 the role of temporal abiotic variability as a driver of invertebrate community composition in agricultural ditches is investigated by analysing monitoring data covering 84 ditches and three soil types (sand, peat and clay). We examined correlations between abiotic conditions (variability and average values of parameters) and macroinvertebrate diversity, determined as local ( $\alpha$  diversity), species-turnover ( $\beta$  diversity) and regional diversity ( $\gamma$  diversity). In addition, functional community responses were examined by analysing the expression of insect life-history strategies in relation to abiotic conditions. This study shows that abiotic variability of nutrients and macro-ions was significant in structuring aquatic invertebrate diversity in the drainage ditches and the effect was scale dependent. In addition, the response of different species could be related to their life-history strategy.

This thesis provides an overview of the interrelationships between different fractions of the ecosystem in North Holland's intensively managed agricultural drainage ditches. It has been demonstrated that both submerged and emergent vegetation strongly influence invertebrate assemblages. Moreover, specific abiotic factors driving invertebrate diversity in these waters are associated with the inlet of mineral rich, river derived water and include concentrations of nutrients, bicarbonates and sulphate. Nutrients and macro-ions cause degradation of peat soils, leading to the accumulation of amorphous layers of mud in remnant peatland environments. In addition, temporal abiotic variability is structuring macroinvertebrate taxonomic and functional composition in the landscape.

Agricultural intensification is placing increased pressures on aquatic ecosystems, via inputs of nutrients, suspended sediments and water abstraction. In the province of North Holland the demand for water is leading to greater influence of mineral rich waters which is ultimately degrading the aquatic environment. Moreover, the annual removal of vegetation is weakening the plant community which is already stressed by eutrophication and turbidity and this has a knock-on effect in causing a decline in invertebrate diversity. Despite the implementation of habitat improvement schemes, such as nature friendly banks in the Netherlands, there appears to be a lack of evidence supporting their effectiveness in promoting biodiversity. The isolation and size of these habitat creation measures are likely to be partially responsible. Small patches of suitable habitat, surrounded by a matrix of intensively managed agricultural land limit the ability of species to colonize these isolated habitats. For management strategies to successfully increase

biodiversity in agricultural landscapes the requirements of habitat size and quality for biota must be met. Fortunately, with the large number of ditches and canals in North Holland's landscape there is good potential to provide the habitat necessary to support a diverse range of aquatic biota, granted management seeks to do so.