Recent insights into the use of invertebrates as indicators of habitat quality

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Abstract: Invertebrates are an important part of aquatic and terrestrial systems, and are, thus, useful as indicators of environmental changes. Habitat quality can be assessed by noting changes in species composition, and relative abundances, using various indices, and by alterations in physiology and morphology of what are known as indicator species. Research shows that invertebrates can be used to indicate if habitat conditions have changed, either worsened or improved. This is why identifying indicator species is crucial. This article covers some recent findings of how invertebrate organisms can be helpful in aquatic and terrestrial ecosystems in indicating ecosystem and habitat deterioration. We also discuss what makes a good indicator species and the types of taxa that have been used in this way.

Introduction

Conservationists have been concerned over habitat degradation on land and in water, for many years now. Habitat quality is important for both plants and animals in the environment but it is also significant for humans. Pollutants in water and soil can enter the human food chain compromising the food supply, drinking water, and inevitably, human health. Modified ecosystems also have implications for species diversity and may threaten the survival of species that have specialized requirements and cannot easily adapt to changes. Aquatic ecosystems where indicators are used include freshwater and marine environments. Terrestrial ecosystem indicators are useful for assessing soil and vegetation quality.

Why aquatic system health is important

The degradation of both freshwater and marine systems has ramifications for biodiversity and also for humans. People depend on water for irrigation in agricultural systems and also consume fish and macroinvertebrates harvested from water systems. There are multiple recreational uses of water such as swimming, water skiing, and scuba diving, to name a few. Polluted waters, thus, pose a threat to humans and also species that may be sensitive to environmental perturbations.

Species that make good aquatic indicators

Indicator species have been found for both marine and freshwater systems. Species that make good indicators are sensitive to environmental change. Changes in water parameters such as pH, water hardness, turbidity, and chemical concentrations can alter the relative abundances of some species. Besides these abiotic factors, biotic factors also impact species. Changes to food sources like algae, phytoplankton, and aquatic macrophytes can all affect aquatic species. Trophic interactions can also change as a result of altered predator and prey interactions and this can have a cascading effect on an ecosystem (Gallindo et al, 2021). Knowing which species of animals to use to indicate such changes is useful for conservationists.

Aquatic indicators and climate change

Even the impact of global warming can likely be evaluated using invertebrates by knowing what temperature thresholds different species have (Sunderman et al., 2022). Water temperatures influence oxygen levels so it is not surprising that changes in environmental temperature could impact invertebrates in an aquatic system. Sessile organisms such as those making up coral reefs are notable for being sensitive to environmental changes. The corals are, therefore, good as a warning sign that conditions

are worsening in an area (Carriger et al., 2021). Bleaching of corals is an indication of a deterioration in conditions including unusual changes in water temperatures.

Marine indicators of pollution

Macroinvertebrates in the ocean are highly sensitive to chemical pollutants and are, therefore, considered useful bioindicators (Deidda et al., 2021). Marine benthic organisms are used to show the impact of pollutants such as sewerage discharge into water (Culhane et al., 2019). A discharge of sewerage into the ocean may increase the abundance of species that do well in such conditions while decreasing the abundance of other species. There was such a change in species assemblages off the coast of Scotland due to such sewerage effluent (Culhane et al., 2019). Sudden nutrient enrichment due to effluent can also trigger algal blooms. An overgrowth of algae has cascading effects through a food web and can increase anoxic conditions making it difficult

for the survival of certain species. There are few insects in the oceans, so invertebrates such as mollusks and crustaceans are used as indicators. The impact of effluent discharged into marine waters does influence communities of crustaceans, nematodes, and annelids (Andrew-Priestley et al., 2022). The abundance of these taxa along with traditional indices should be used to monitor environmental impacts in specific regions. Traditional indices include the species richness and Shannon diversity index; these are both useful measures of biodiversity. In the oceans, bivalves are valuable indicators that are sensitive to chemical pollutants; the bivalves often show a change in their endocrine system in the presence of chemicals (Fernandez, 2019). This is significant because mussels are harvested as human food, meaning that the presence of chemical pollutants could compromise the safety of this and other marine food items for human consumption since chemicals bioaccumulate and biomagnify through the food chain.
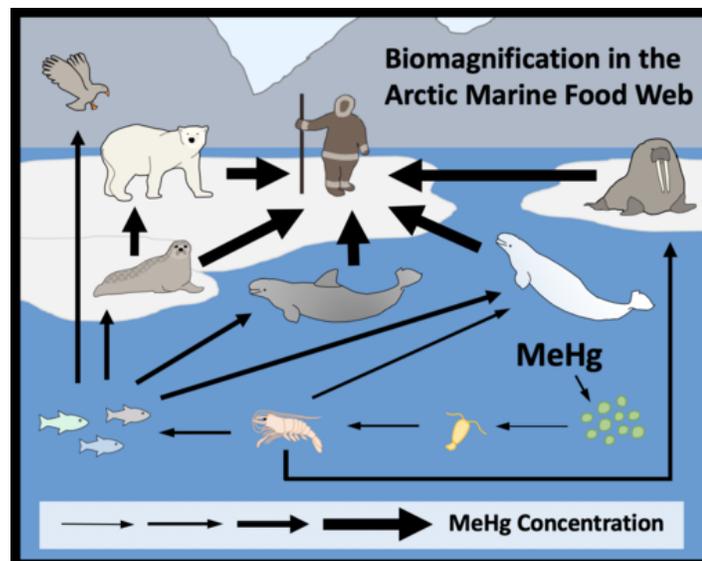

Figure 1: An example of biomagnification of methylmercury in the Arctic marine food web; image is from Wikimedia commons**.**

Freshwater indicator invertebrates and insects

In freshwater systems, invertebrates have been considered good indicators of habitat quality. There are many more insects found in freshwater compared with saltwater, which is why it is not surprising that insects have been used in the past as bioindicators. An assortment of insects occurs in fresh water, including dragonflies, mayflies, stoneflies, bugs, and beetles. Many insect groups, specifically mayflies,

stoneflies, and dragonflies have commonly been used as indicators of water quality. Recent studies have tried to determine if traits of invertebrates rather than individual taxa will work better to show agricultural chemicals in water bodies. The results still indicated that the taxa level is most useful (Collins and Fahrig, 2020). For instance, the bugs in the family Corixidae were associated with lower nitrate levels in the water.

Aquatic species and restoration efforts

Aquatic invertebrates, particularly, insects can be used to monitor the effectiveness of restoration efforts in wetlands and streams. For instance, a restored stream in China showed almost 50% of the taxa found in a natural undisturbed stream after about 4 years also occurred in a restored stream. Specific species of damselfly and biting midges were found to be good indicators of the restoration success (Lu et al., 2021). In other cases, crustaceans have been used along with fish, to assess restoration efforts. This was the case in the Florida everglades (Trexler and Goss, 2009). Often it takes some time before restored aquatic ecosystems show substantial recovery of species. This was the case for restored rivers and wetlands in Germany, where it was noted that taxa such as dragonflies did not immediately recover (Schulz-Zunkel et al., 2022). Another idea is that more than one indicator should be used and that biotic variables along with measures of abiotic factors like water chemistry be measured to monitor the recovery of degraded habitats.

Species that make good terrestrial indicators

Pollinator species are useful as indicators of terrestrial systems. One reason is that these species indirectly indicate changes in vegetation. Some arthropods are thought of as good indicators in terrestrial systems because they are abundant enough, relatively easy to sample, and in some instances, also easy to identify to species level. It is also valuable if a species is breeding in the habitat, for instance, a leaf beetle which is also found to have larval and pupal stages. This provides more insight into the habitat and its suitability to support some types of invertebrate biodiversity. Myriapods are not thought of as useful when it comes to indicator species on land because they are not normally very abundant and may be harder to sample.

Terrestrial indicators for chemical pollutants

The quality of terrestrial habitats is also relevant and impacts biodiversity and humans. Invertebrate species' presence, absence, and relative abundances are useful to use as evidence that conditions are deteriorating in an area. In time a decrease in biodiversity or radical change in species composition can signal problems in an area. Changes in pollinator species may impact agriculture since many crops and orchards have plants that rely on insect pollination. The decrease in bees is already a concern globally and one factor may be the use of pesticides in agriculture which could have both lethal and non-lethal, yet detrimental effects (Belsky and Joshi, 2020). Pollutants may also impact insects in ways other than reducing the numbers of individuals. For instance, the morphology and physiology of caterpillars and aphids are altered by the presence of heavy metals (Skaldina and Sorvari, 2019). The problem with pollutants is that these chemicals don't only impact invertebrates. They end up in the tissues of vertebrates that prey on insects and other invertebrates in the environment. For example, polychlorinated biphenyls and polybrominated diphenyl ethers bioaccumulated in songbirds that were feeding on contaminated invertebrates (Wu et al., 2022).

Soil invertebrate indicators

Invertebrates living in the soil of a terrestrial habitat play a crucial role in breaking down material, recycling nutrients, and aerating the soil. When most people think of soil invertebrates they focus on earthworms, which are known to be helpful for the soil. However, there are also arthropods that are an important part of soil fauna. The mites, Acari, and springtails, Collembola are often the most numerous of the soil arthropods (Menta and Remeli, 2020). Beetles and flies can be useful as indicators of soil condition, especially where larvae occur in the soil. One of the more useful indicator groups for soils is ants. Ants that nest and live in the soil respond to changes in parameters such as humidity. The number of ant nests can even be used to show the quality of the soils (Menta and Remeli, 2020). Orthoptera are indicators of terrestrial conditions, but are better at indicating conditions in grasslands. They are sensitive to industrial pollution and often the populations are greatly reduced in such areas.

Terrestrial arthropods as indicators of forest condition

Using indicators of forest condition is important in countries in Europe where the plan is for sustainable forest management (Oettel and Lapin, 2021). Butterflies are good bioindicators for land disturbance, including for showing the degradation of forests. Species changes often occur among butterflies in response to a modified habitat (Kyerematen et al., 2018). Species assemblages change so that the presence and relative abundances of Lepidoptera change as the landscape changes. Scientists found this in areas being mined in Ghana. Mining activity

and forest degradation resulted in an increase in savanna and open-area species of butterflies while there was a drop in typical forest species. An advantage of using butterflies as indicators is also that they are relatively easy to identify and sample. This makes it a feasible option for assessing ecological change.

Terrestrial insects and restoration efforts

Invertebrates can also be used to show the effects of ecological restoration efforts (Borges et al., 2021). Certain insect groups are known to be sensitive to changes and are, therefore, good indicators of deterioration but also restoration of habitat. Such groups include the Hymenoptera (bees, wasps, and ants), Coleoptera (beetles), and Lepidoptera (butterflies and moths)(Parikh et al., 2021). These insects are also important pollinators, and a reduction in the numbers of these insects may be detrimental to local vegetation. A restored habitat should show healthy biodiversity including the groups already

mentioned, but also an increase in general species diversity.

Conclusions

Invertebrates are useful as bioindicators of habitat conditions in both aquatic and terrestrial systems. Climate change can also alter species assemblages as shown by coral reefs. Pollutants in water and in soils can alter population numbers, species diversity, and also morphology and taxonomy of indicator species. Chemical pollutants can enter the human food chain when people feed on contaminated marine invertebrates such as mussels and crabs. Similarly, freshwater fish may bioaccumulate toxins from invertebrates they feed on. Changes in terrestrial systems indirectly threaten human health and the food supply by affecting important pollinators like honey bees. Invertebrates can also be used to check on the progress of ecological restoration efforts, both in aquatic and terrestrial systems.

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Conflicts of Interest

The authors state no conflict of interest.