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INSECTS AS INDICATORS OF ENVIRONMENTAL CHANGING AND POLLUTION: A REVIEW OF APPROPRIATE SPECIES AND THEIR MONITORING

OS INSETOS INDICADORES DE ALTERAÇÃO E POLUIÇÃO AMBIENTAL: UMA REVISÃO DAS ESPÉCIES ADEQUADAS E DO SEU MONITORAMENTO

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ABSTRACT

Responses of some species to disturbances can be used as a parameter of analysis about levels of change in the environmental services. These species can be used as environmental bioindicators. Class Insecta has many appropriate species. This paper aims an analysis of bioindicator species of the impact caused by intensive agriculture, deforestation, reforestation and pollution of aquatic and terrestrial environments.
Keywords: Bioindicators. Insecta. Environmental polution. Monitoring.

RESUMO

A resposta de algumas espécies animais e vegetais às perturbações pode ser utilizada como parâmetro de análise quanto aos níveis de alteração do funcionamento dos serviços ambientais, e por isso são consideradas bioindicadoras das alterações ambientais. No entanto, algumas espécies respondem mais fidedignamente do que outras a estas alterações. A classe Insecta possui muitos representantes adequados para este tipo de análise. Este trabalho objetiva a análise das espécies consideradas

bioindicadoras das consequências causadas pela agricultura intensiva, pelo desflorestamento, reflorestamento e pela poluição de ambientes aéreos, aquáticos e terrestres.
Palavras-chave: Insecta. Bioindicadores. Alteração ambiental. Poluição. Perícia ambiental.

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1. INTRODUCTION

There was a growing change of natural environments around the world, as a result of the growth of human population in recent decades. The economic potential of biodiversity and advanced destruction process of land ecosystems, especially in tropical regions, led to the search for an extinction rate estimation of plant and animal species, which are around 27,000 per year (ANDRADE, 1998; CHEY et al., 1997).

Invertebrates are more severely and quickly affected than other taxa by changes in the landscape. The insects are responsible for many processes in the ecosystem and its loss can have negative effects on entire communities. Thus, a strong understanding of insect responses to human activity is necessary both to support policy decisions for conservation and to evaluate functional consequences of human disturbance on ecosystems (NICHOLSA et al., 2007).

Studies about biodiversity preservation in ecosystems can provide information about maintenance of environmental resources and sustainable development. Insects are the most abundant animals in almost all ecosystems and can be used to evaluate the impact of environmental change. Through population and behavioral studies and the taxonomy of species, it's possible to estimate what the current degradation rate is and its future consequences. This paper aims to analyze the major groups of insect indicators on the aquatic and terrestrial environments.

2. ECOSYSTEMS MONITORING WITH BIOINDICATORS SPECIES

Currently, a relevant question is whether fragmented environments can preserve the diversity and abundance of insect species such as the high degree of endemism observed in wild areas. In addition to what would be the fragmented environments consequences on generalist species populations, which are an important link in the food chain and development of plant species for pollination.

Many arthropods are used for bioindication because: a) the most frequently collected taxa (such as beetles and spiders) are polyphagous predators and are considered important for the biological control, b) collections are made easily with pitfall traps, and c) catches are usually large enough to allow statistical analysis. According Martos et al. (1997), environmental indicators are quantitative and qualitative parameters able to show changes in the environment, where physical, biological, chemical or human phenomena are not studied alone, but together in the complex dynamics of the environment.

Entomofauna studies to furnish information about ecosystems conservation status their productivity and levels of water contamination and pollution. Therefore, bioindicator species identification is essential, due to the important role that these organisms have as transformers and regulators of ecosystems (BROWN, 1991; CAMERO and CHAMORRO, 1995 apud RUBIO, 1999).

Concern with environmental issues has raised the demand for bioindicators able to reflect their environment. Among these organisms, the insects may contribute to a practical assessment of the sustainability degree (LOPES, 2008). According Tylianakis et al. (2004), indicator insects become particularly useful because they represent more than half of all species and their diversity allow assessing the difference between habitats on acceptable refined scale. Insect groups used as environmental bioindicators should have the characteristics shown in the Table 1.

Table 1 - Insect groups characteristics used as environmental indicators

Characteristics	Description
Richness and species diversity	Four in five species of animals are insects
Easy handling	Most species require few efforts for their capture, except toxic species. The small size of samples helps to their capture and transport;
Ecological faithfulness	Many species may have low tolerance to abiotic factors, which allows to link certain insect groups with certain habitats;
Fragility to small changes	It allows to select demographical or behavioral variables that can be measured or observed in the field, and have a close correlation with the pre-selected abiotic variables;
Organism's responses	To identify levels of environmental change.

Modified from Andrade (1998); Peck et al. (1998).

Requirements for aquatic insects groups to be considered environmental quality bioindicators differ slightly from the characteristics attributed to bioindicators in land environments. According to Peck et al. (1998), the bioindicators are: a) Respond quickly to environmental changes; b) Have few generations per year; c) Are easily sampled and identified; d) Show high sensitivity for detecting early changes in their geographical area; e) Provide information without interruption of the extent damage caused by environment alteration or pollution.

Some taxonomical and sampling difficulties have restricted the use of several species of Coleoptera (beetles) and Homoptera (bugs) Orders as environmental bioindicators, especially in the tropical region (HOLOWAY, 1983 apud CHEY et al., 1997). These concerns were also demonstrated by Carlton and Robison (1998) with subfamily Aleocharinae (Coleoptera: Staphylinidae) due to the large number of undescribed taxa and the lack of reliability on those already described. Moreover, Frouz (1999) reported as one of the disadvantage to the use of Diptera species (flies), as environmental bioindicators, the great taxonomic difficulty, especially in their larval stage.

3. BIOINDICATOR INSECT GROUPS

Several aquatic insects groups can be used as aquatic environment bioindicators (Table 2). Odonata (dragonflies) species are very sensitive to changes caused to their habitat, especially lakes and flooded drainage areas (CORBET, 1980). Hamilton and Saether (1971) and Hardersen (2000) reported the potential of aquatic insects as indicators of water quality. Several other species of the families Gyrinidae, Dytiscidae, Hydrophilidae (Coleoptera), Notonectidae, Veliidae (Heteroptera) and Plecoptera and Ephemeroptera Orders have high adaptive capacity, colonizing most of the environments and occurring throughout the year, reflecting ecological and geographical changes, and hence their conservation status.

The tolerance of aquatic organisms to heavy metals has been explained by the metallothioneins (MTs) formation in many aquatic organisms. If the presence of MTs is a measure of metal tolerance, the measurement of MTs could provide clues about the tolerance in this organisms and possible toxic agents responsible for environmental stress (BISTHOVEN et al., 1998). However, insects are less used as pollution bioindicators by metals, although species of the genus *Halobates* are suitable for bioindication of cadmium and mercury (NUMMELIN et al., 2007).

Land insects are good bioindicators in various types of environmental change (Table 2). The Order Coleoptera represents approximately 20% of the total diversity of arthropods and plays roles in maintaining soil quality, population regulation of other invertebrates and energy flow, and contributes to the physical and chemistry soil formation (CARLTON and ROBISON, 1998). Nummelin and Hanski (1989), Nestel et al. (1993), Louzada and Lopes (1997) and Davis (2000) confirm beetles species (Coleoptera: Scarabaeidae) have a high potential as environmental indicators in forest area or agricultural crops.

Beetles from Order Coleoptera and Family Carabidae are important predators. They participate of biological control, biological monitoring of pollution from oil, sulfur, herbicides, CO_2, insecticides and radioactive phosphorus.

The moths and butterflies (Lepidoptera), besides having basic requirements, have ecological faithfulness in temperate and tropical regions and are very sensitive to changes in the environment (GILBERT, 1984; ANDRADE, 1998). The habitat mosaic maintenance that includes primary forests and other changed areas with different change levels was the strategy suggested by Wood and Gillman (1998) to protect Lepidoptera diversity in natural environment management (WOOD and GILLMAN, 1998).

Some lepidopteran groups are used as environmental pollution indicators by heavy metals and carbon dioxide (CO_2 concentration) in locations close to industrial areas and even within urban areas. Presence and consequences of copper, iron, nickel, cadmium, sulfuric acid ions and other substances used in fertilizers were studied with pupae of different Geometridae and Noctuidae species (HELIÖVAARA and VÄISÄNEN, 1990), Eriocraniidae populations (KORICHEVA and HAUKIOJA, 1992), cycle duration and newly hatched larval mortality rate from butterflies (Family Nymphalidae), which feed on plants subjected to high CO_2 concentrations (FAJER et al., 1989).

Collembola are primitive insects that influence soil fertility through microbial activity stimulation, the fungi spore distribution and inhibit fungi and bacteria action causing diseases in plants (SAUTER and SANTOS, 1991; RUSEK, 1998). They are very sensitive to changes in the soil and diversity reduction can show us pollution by heavy metals, pesticides in agricultural soils and soil water acidification by organic pollutants and waste (RUSEK, 1998).

Ants are used as soil quality bioindicators and have a key role in the recovery of degraded and reforested areas (MEJER, 1984). This group, which is very sensitive to human impact, could be used as environmental indicators in different ecosystems (FOLGARAIT, 1998; PECK et al., 1998). Depending on the degree of the environmental change, many expert species are extinct of the site, encouraging the establishment of dominant, aggressive and generalist species, which can be used as indicators of disturbed habitats (READ, 1996). The ants presented a strong resistance to pollutants (radioactive and industrial pollutants) that may be because only about 10% of individuals fall outside the nest and exposed to the harmful pollution effects (PETAL, 1978). Peck et al. (1998) suggest that some ant groups have potential as biological indicators of soil conditions, crop management and assessment systems for plantations in agroecosystems. The impact of ants in soil is demonstrated by leaf cutting ones in the tropics, where they are the most important agent of change in the soil, contributing to improving physical and chemical quality (CHERRET, 1989).

Order Diptera is a very heterogeneous group and there are some restrictions on its use as bioindicator because of the lack of ecological knowledge of many groups of flies. However, some flies species are considered good environmental change bioindicators. Bartosova et al. (1997) showed the potential of species from the Family Sarcophagidae as environmental pollution indicators by heavy metals, asbestos fibers and waste chemicals. However, due to variability in the flies' sensitivity to insecticides and herbicides, Frouz (1999) recommends that one must be careful when using some species of flies as chemical indicators of contaminated soil.

Family Syrphidae, one of the largest families of Diptera, has wide distribution, well known taxonomy and its larvae require different environmental conditions, which makes these flies' good bioindicators. Due to environmental requirements of their larvae, these insects are particularly affected by the landscaping diversity reduction (SOMMAGGIO, 1999).

Most of the research on pollinators as bioindicators have been on population level and have focused mainly on bees. The pollinator strength and its population size are generally considered the most important features for plant reproduction, especially to the agricultural crops (KEVAN, 1999). Pollinators, especially honeybees (*Apis mellifera*), are considered reliable biological indicators because they show environment chemical impairment due to high mortality rate and intercept particles suspended in air or flowers. These substances can then be detected using methods of analysis (GHINI et al., 2004).

Table 2 - Bioindicator insect groups from aquatic and land environments and their role in the monitoring.

Group	Common Names	Biomonitoring	Habitat
Odonata Order	dragonflies and damselflies	water quality	aquatic
Gyrinidae Dytiscidae Hydrophilidae Notonectidae Vellidae Families	whirligig beetles predaceous diving beetles - backswimmers -	due to high adaptive capacity	aquatic
Ephemeroptera Plecoptera Orders	mayflies stoneflies	due to high adaptive capacity	aquatic
Halobates	ocean-skaters	cadmium and lead	aquatic
Coleoptera Order Scarabaeidae Family	beetles	in forest and agricultural crop	land
Coleoptera Order Carabidae Family	beetles	biological control oil, sufur, herbicide, CO_2, insecticide pollution	land
Lepidoptera Order	moths and butterflies	more sensitive environmental changes heavy metals and CO_2 pollution	land
Collembola Order	springtails	pollution by heavy metals, pesticides and water acidity	land
Formicidae Family	ants	degraded and reforested areas recovery	land
Diptera Order Sarcophagidae Family	flies and mosquitos	heavy metals	land
Diptera Order Syrphidae Family	flies and mosquitos	are affected by diversity reduction	land
Apis mellifera	domestic bees	chemical environmental changes	land

4. BIOINDICATOR INSECTS IN AGRICULTURAL AND FOREST AREAS

Cultivated areas or reforested areas with some diversity of plant species have shown high insect species diversity and greater ecological stability, where the competition for resources is intense, preventing the prevalence of few dominant species (CHEY et al., 1997; DORVAL, 1995; MEZZOMO et al., 1998).

Explanations for loss of species in agricultural environments are: changes in microclimatic conditions, foraging activity and nesting locations, reduced food availability from the use of agrochemicals and interactions with other species (DE BRUYN, 1999).

Monoculture is predominant in agricultural areas. In these areas there are many populations of defoliator and sucking insects, characteristics of unbalanced environment (ABATE et al, 2000). The use of fertilizers and chemicals is responsible for the decline of biodiversity in simplified agricultural systems since it eliminates a large number of insects acting as biological control agents.

Hymenoptera communities are common in agricultural areas. They act as crops and wild plant pollinators. Furthermore, many species that live in society are predators or parasitoids, acting as of biological control agents (TYLIANAKIS et al., 2004).

We should consider the adoption of environmentally correct practices in areas under agricultural management. The aeration depth control could prevent layers destruction, where the activity of decomposer organisms (Collembola, Coleoptera) is intense. The rational use of products to soil correction, fertilization and crop residues incorporation can improve the organic soil part and provide optimal conditions for decomposer insects and nitrogen fixing bacteria, increasing insect biodiversity. Nummelin and Hanski (1989), Nestel et al. (1993), Perfecto et al. (1997), Honek and Jarosik (2000) confirm the importance of cultural diversity for the preservation of the diverse insect groups characteristic of not much changed areas.

In the forest, the imbalance begins with native vegetation replacement, which normally has high insect diversity, for homogeneous plantation areas, where ecological balance is fragile and insect diversity is reduced. Therefore, the number of harmful insect species is quite high and frequently occurring population booms, especially of defoliator lepidopteran (DORVAL, 1995).

The reforestation is usually located in nutrient-poor soils, and at certain times of year the trees are exposed to water stress, becoming highly susceptible to attack by insects. During this period there may be population booms of aggressive and dominant insects.

Remaining strains of trees selective logging can serve as a host material, providing favorable conditions for occurrence of dominant Scolytidae species (ambrosia-beetle) population booms. Moreover, there is the fire that destroys important soil layers, causing damages and weakening the trees, becoming them susceptible to attack by insects.

Therefore, the occurrence of harmful and dominant insect species in agricultural and forest environments may be environmental imbalance evidences, caused by changes in biotic and abiotic factors (Table 3).

Table 3 - Difference between agricultural and forest areas during biomonitoring

Agricultural Area	Forest Area
defoliator and sucking insects	deforestation increases number of harmful insects
diversity reduced due to fertilizers	deforestation decreases insect diversity
pollinators: bees and wasps	reforestation occurs in poor soil, increases water stress and insects attacks
Social species: biological control	remaining strains: host material to ambrosia-beetle Fire: destroys soil and trees

5. INSECTS AS BIOINDICATORS OF ENVIRONMENTAL POLLUTION

Many insects can be used as environmental pollution bioindicators (Table 4). Ants have been used to measure pollutant concentrations in borealis forests and Australia, and are currently used to monitor disturbed ecosystems. Bees are considered one of the most versatile and efficient bioindicators. They are used to monitor trace metals in urban environments, radioactivity after the Chernobyl disaster, pesticides and herbicides effects, industrial wastes and pollutants (URBINI et al., 2006).

Many studies have demonstrated deformities in larvae from several genera from the Family Chironomidae (eg *Procladius*, *Chironomus* and *Cryptochironomus*) and the results indicate that the abnormalities are strongly associated with polluted sediments (SERVIA et al., 1998). Gerridae are indicated to detection of different iron and manganese concentrations, but seem less suitable for nickel and lead accumulated (NUMMELIN et al., 2007).

Wasps from the *Polistes* and other social wasps are at the top of the food chain and, therefore, are exposed to dangerous biological concentration. As its mass larval fecal can accumulate lead up to 36 times the adult body, these wasps seem to be a promising species for pollution by lead biomonitoring (URBINI et al., 2006).

Table 4 - Insects groups used as environmental pollution bioindicators

Groups	Biomonitoring
bees	trace metals, radioactivity, pesticides, herbicides and industrial pollutants
ants	polluent concentration at Australia
Larvae Family Chironomidae	iron and manganese concentration
Genus *Polistes* (wasps)	lead pollution

6. OTHER BIOINDICATOR INSECT GROUPS

According to Eggleton et al. (1994), termites are important decomposers in land ecosystems. Its activity increases soil infiltration capacity, leading to water retention and soil productivity. In forests, they play a role in plant origin material and organic soil decomposition and incorporation. In agricultural, pasture and reforestation areas they are not always perceived because its nests are underground, and their presence is only noticed by the damage they cause to the plants.

Aphids are pollution indicators, because they show an increase in their population density when feeding on hosts exposed to environments with high CO_2 concentrations. However, studies showed no significant correlation between CO_2 increase and Homoptera population density (CANNON, 1998).

7. CONCLUSIONS

The use of bioindicators is essential for environmental monitoring. The main characteristics of a bioindicator are: richness and diversity species, easy handling, ecological faithfulness, fragility to small environmental changes and good organism responses. Class Insecta has all of them. However, some species respond better than others to these changes and according to the environment.

In the aquatic environment, Odonata species are more sensitive to environmental changes in the water. Coleoptera, Heteroptera, Plecoptera and Ephemeroptera have high adaptive capacity. In the land, Coleoptera Order has many bioindicator species, for example Scarabaeidae Family (beetles) in forest and agricultural cultures. Some Lepidoptera and Diptera groups are used as heavy metal pollution indicators.

Agricultural and forestry systems have shown high insect diversity and better ecological stability in relation to monoculture. The use of fertilizers and chemicals reduces biodiversity in simplified agricultural areas. In the forest, the imbalance begins with replacement of native vegetation, in areas of homogeneous plantations. Therefore, it increases the number of harmful insects, especially defoliator lepidopteran.

In environmental pollution, bees are used to monitor trace metals in urban environments, radioactivity, and pesticide and herbicide effects. Gerridae detect different iron and manganese concentrations.

Therefore, this study concluded that the Class Insecta has many potential representatives that can be used as environmental bioindicators, among which are some species from the Coleoptera, Diptera, Lepidoptera, Hymenoptera, Hemiptera, Isoptera Orders and others.

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