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Environmental demands for sustainable regulation schemes in the humid tropics

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Abstract Water is one of the most important natural resources in many countries of the humid tropics. It supports many socio-economic activities and provides a renewable energy source for economic development. Sustainability of water projects includes maintenance of biodiversity. Consideration of environmental demands in the basins is an essential component in regulation schemes. This study utilized an Expert Panel Approach to select indicator species for a sustainable runoff in a tropical environment of Costa Rica and to identify their environmental demands. A ranked list of indicator species, chosen based on their sensitivity to changes in river flow caused by regulation, was suggested by experts on tropical flora and fauna at the first expert panel. The second expert panel defined environmental demands of the proposed indicator species in terms of water depth, stream velocity and substrate type. The information obtained provides the necessary background for evaluation of the impact of different regulation schemes on the aquatic environment.

Key words indicator species; habitat preference; Expert Panel Approach; environmental demands; sustainable runoff

INTRODUCTION

Water is one of the most important natural resources in many countries situated in the humid tropics. It supports many socio-economic activities and its development provides a renewable energy source for economic growth. The sustainability of such development also includes the maintenance of biodiversity. Consideration of environmental and social demands in the basins is an essential part in regulation schemes. Using bio-indicators as an early warning of degradation in an ecosystem can help sustain water resources. Indicators are groups or types of biological resources that can be used to assess environmental conditions. There has been a rapid increase in the number of studies devoted to developing biological criteria for sustainability during recent years (e.g. Hirvonen, 1992; Nip *et al.*, 1992; Lovejoy, 1994). Biological indicator species are species that are particularly sensitive to disturbances and are essential for the maintenance of biodiversity. Their decline may indicate a disturbance that alters the ecosystem. Which species are selected depends on the questions being posed and especially whether one aspect of an ecosystem is monitored for a specific purpose. Using biological indicator species is particularly useful when the extremely rich biodiversity of a system (e.g. the Costa Rican humid tropics environment) makes it difficult to assess the whole bio-community.

Selection of indicator species can be approached in different ways. They can be chosen based on literature surveys for analogue environments or based on the experience of long-term monitoring of habitats. Judging from the scientific literature, Costa Rica is rather well known in terms of its aquatic and riparian biological communities (e.g. Wootton & Oemke, 1992; Ramirez & Pringle, 1998). Literature references offer useful data sources but this information was not sufficient for the choice of indicator species as it has been collected for different purposes. This study is part of the project "Estimation of minimum acceptable (compensatory) flow for the rivers of Costa Rica" (Laporte *et al.*, 2006) with the aim to develop sustainable water regulation schemes for low flow conditions in tropical environments. Information from the literature has been used in this study as a complement to other sources.

The time schedule of the project excluded long-term monitoring possibilities. That is why an Expert Panel Approach (EPA) has been used here to identify the indicator species for the particular aim of the project and to describe their habitat demands. The EPA approach is a well-established scientific tool used in many disciplines and also in hydrology and ecology (e.g. Marcot *et al.*, 1997; Kumar *et al.*, 2002). This paper presents the procedures for selecting indicator species for the humid tropics and identification of their habitat demands for developing criteria for sustainable water regulation schemes under low flow conditions. Field sampling in two case-study basins will be used for validation purposes.

INDICATOR SPECIES FOR INSTREAM FLOW

Certain fish, terrestrial vertebrates that are dependent on an aquatic system and macro-invertebrates can be used as indicators of ecological runoff conditions in a river. Among those, migrating species have a capacity to reflect conditions in larger areas than those that permanently stay in a limited area and thus reflect the conditions only there. This is why fish are often used when defining the biological integrity of streams and rivers, i.e. the overall functioning of lotic ecosystems (Angermeier & Karr, 1986; Davis & Simon, 1995). The species chosen should provide standards of consistency and precision about changes in a community and they should be reliable enough so that changes and trends are detected unambiguously (Watson *et al.*, 1995). Selection of biological indicators must also be guided by the uses to which the indicators will be put. A number of general attributes have been suggested for indicator species (Hutcheson *et al*., 1999), such as:

(a) being sensitive to change over a short time-frame within the period of measurement;
(b) being widespread through the study area;
(c) being widespread through time and not just ephemeral;
(d) having occurrence related to dynamic processes or functions;
(e) being clearly measurable, e.g. in size, abundance, growth, structure or frequency;
(f) being cross-referable to other indicators, while having independent attributes.

The use of EPA may offer a good solution considering the difficulty of the selection task. The EPA has been used in this study for this purpose. A group of 15 experts in tropical flora and fauna with a background in both academia and operative services were invited to the EP. As a first step, the experts worked individually to select and recommend the indicator species with a view to the aim of the project. The selection of indicator species was based on their tolerance and sensitivity to changes in river flow as a result of regulation. Tolerance and sensitivity to the following effects was considered: interruption of migration possibilities; impact on physiological processes; decrease of the wetted perimeter; collapse of the associated wet areas; and change of trophic conditions. The tolerance and sensitivity were graded from one to ten, the latter describing the highest grade of sensitivity. As complementary criteria, species abundance and habitat abundance were ranked to ensure that it is possible to easily find the indicator species. In the second phase of the panel an open discussion of the suggestions from individual experts took place to reach a consensus. Three species in each group (*Mammalia*, *Aves*, *Amphibia*, *Reptilia*, *Osteichthyes*) that obtained the highest summary grade were then selected as indicator species. As the fish group was chosen as a focus in the investigation, six indicator species were suggested for this group. Table 1 shows the list of indicator species suggested in this study.

Table 1 List of the selected indicator species.

Group	Family, genus or species	Common name
Mammalia	*Noctilio* sp	Bats
	Lutra longicaudus	River Otter
	Procyon sp	Racoon
Aves	Ardeidae	Egrets and herons
	Alcedinidae	Kingfisher
	Phalacrocoracidae	Cormorant
Amphibia	*Bufo* sp	Toads
	Smilisca sordida	Tree frog
	Centrolenidae	Glass frogs
Reptilia	*Rhinochlemmys*	Fresh water turtle
	Basiliscus sp	Jesus Christ lizard
	Leptophis sp	snake
Osteichthyes	*Joturus pichardi*	Hog mullet
	Sicydium altum	Gobiid
	Parachromis dovii	Rainbow bass
	Agonostomus monticola	Mountain mullet
	Brycon sp	Tetra
	Poecilia gilli	Molly

HABITAT PREFERENCES FOR INDICATOR SPECIES

Identification of the habitat preferences of the indicator species is of a great importance while developing criteria for sustainable flow regulation. Similar to the selection of indicator species, such information can be obtained from the literature, from long-term habitat monitoring or by means of Expert Panels. No long-term monitoring was feasible in the time frame of the project but a two-year long field measurement programme has been started in two case-study areas in order to provide validation data for habitat demands. Previous studies described in the scientific literature were used in this study for terrestrial vertebrates and macro-invertebrates. For the fish that were the focus of the study, the EP approach has been chosen. This allows use of the knowledge accumulated by experienced specialists during many years of work in the field that often has not been documented in publications. For validation based on field data, one fish species, the Mountain Mullet (*Agonostomus monticola)*, common in Costa Rica and also in other parts of the world, has been chosen. Other species were also considered for validation purposes: Hog Mullet (*Joturus pichardi)* that was highly ranked by the first EP. However, this species is found primarily in the basins of the Caribbean slopes of Costa Rica and its population has decreased during recent years.

The second Expert Panel allowed definition of the environmental demands of the proposed indicator species in terms of water depth, stream velocity and substrate type, ranking these as optimal, normal or inadequate. The choice of these habitat descriptors was made with respect to the practical possibilities of acquiring such data, as the basins concerned for regulation in humid tropics as a rule are situated in mountainous areas that are difficult to access. Possible velocities in the rivers of Costa Rica during the limiting dry season were classed in advance as: very slow; slow; moderate; fast and very fast, offering a linguistic "transference" table to the experts. The linguistic classification proved to be much easier for the experts compared to quantitative velocity classes. Six classes of substrate were distinguished: clay; silt; sand; gravels; stones; and blocks. To facilitate the answers for depths and velocities, graphical illustrations were provided. The experts compiled habitat characteristics for each of the chosen indicator species attributing a corresponding category, i.e. optimal, normal or inadequate. Intervals of values were allowed. Table 2 presents the questionnaire suggested to the experts during the second EP and their answers on the example of Mountain Mullet (*Agonostomus monticola)*. All qualitative and quantitative data have been stored in a database as reference material for other environmental studies in Costa Rica.

The information was assembled and discussed at a plenary meeting where the final scheme for characterizing habitat demands for the chosen indicator species was compiled. Using this information fuzzy rules have been developed for further use in combination with a simple hydraulic model to test different regulation scenarios in terms of usable habitat areas in a river (Gottschalk *et al.,* 2006).

Table 2 Questionnaire for the experts at the second EP; example for *Agonostomus monticola*.

Question		Answer		
1.	*What are the general habitat preferences for the species?*	Current from moderate to rapids, with good source of food (aquatic insects). Altitude from the sea level to 800 m.		
2.	*What range do you consider as inadequate, regular and optimum for the species for the following habitat characteristics: substrate, velocity and depth?*	Inadequate	Regular	Optimum
		Velocity:		
		Very slow	Moderate to very strong	Strong
		Depth:		
		<0.25	0.25–0.35; 2.00–3.00	>0.35 – <2.00
		Substrate:		
		Clay and loam	Sand and gravel	Rocks and boulders
3.	*To which factors are species highly sensible according to your opinion?*	Slow currents, excess of sediments, and substrate for insects. Clean waters well oxygenated.		
4.	Comments	Evidence of migratory behavior, the continuity of flow and absence of any kind of barrier are very important for the species.		

Field investigation

As noted earlier, field investigations have been started in two study areas to collect data for validation of habitat demands established with the help of the EPs for two example species: *Agonostomus monticola* and *Joturus pichardi*. The presence of these species was evaluated visually by means of snorkeling in each river section in the two basins of study, at the same time measuring flow velocity and depth and classifying substrate. Information about the characteristics of the ecosystem is also registered. This sampling will be on-going during two years to yield field data about habitat preferences.

CONCLUSIONS

EPA is an effective and low-cost tool for selecting indicator species and establishing their habitat demands in the humid tropics, especially when financial resources are limited and difficult access to rivers limits extensive field investigations. A useful list of indicator species for studies related to minimum acceptable river flow in the humid tropics has been successfully established using EPA. The EPA also identified habitat demands for the selected indicator species. Simple and readily available habitat characteristics related to river flow would allow direct tests of sensitivity of habitats to different flow regulation schemes. The choice of habitat characteristics can be easily adjusted to the needs and practical possibilities of each particular study, while the list of indicator species can be used as a reference for other projects in the humid tropics. Supported by field validation the method provides reliable and indispensable information for testing different scenarios of river flow regulation in search of environmentally sustainable schemes. A similar approach has also been developed for evaluation of the effects of regulation for socio-economic activities in a basin.

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