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ADVANCES IN APPLIED ECOLOGICAL TECHNIQUES

Participatory research methods in environmental science: local and scientific knowledge of a limnological phenomenon in the Pantanal wetland of Brazil

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Summary

1. Participatory research methodologies incorporating local knowledge are important to the success of ecological research and the sustainable management of natural systems. However, methods of this type are not commonly employed in the natural sciences.

2. We adopted a scientifically rigorous ethnographic research methodology to incorporate local knowledge into understanding a natural limnological phenomenon in the Brazilian Pantanal. Known locally as 'dequada', it is associated with fish kills.

3. Using primarily open-ended questions and semi-structured interviews, 30 older head-of-household men were interviewed, by the same interviewer, in a small community representative of the few local riverside settlements. Their opinions were then contrasted with current scientific knowledge.

4. In concordance with the scientific community, the local community cited decomposition of organic material as the principal cause of fish mortality due to the dequada. Local people therefore can have a well-founded understanding of their environment.

5. This study demonstrates the importance of incorporating local knowledge to corroborate and, often, to guide the process of scientific inquiry. In this case, local knowledge added to scientific knowledge by providing a more complete understanding of the management and conservation of a natural system. We recommend that ecologists should be ready to acknowledge that local understanding can be greater than that of 'outsiders'.

Key-words: Brazilian tropical wetland, ethnographic methods, fish kills, limnology.

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Introduction

After decades of top-down economic development models, social science researchers have begun to recognize the importance of involving local people in the management of local resources (Western & Wright 1994; Redford & Mansour 1996). Understanding site-specific and co-evolutionary features of complex human institutions and their natural environmental contexts is increasingly seen as essential to sustainable economic development (Esman & Uphoff 1984; Cicin-Sain & Knecht 1995; Scherr *et al.* 1995). Local people can possess a deep understanding of their own environment cultivated over decades or generations of living (often sustainably) within that context; their knowledge is sometimes beyond that of outsiders (Gray 1991). The effective participation of local people in the policy decisions that most closely affect them, including the management of their natural environment, is one of the key

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factors identified for increasing the probability of sustainable economic development (WCED 1987; IUCN/UNEP/WWF 1991; UNCED 1992). For example, Ramsar Recommendation 6.3, of the Ramsar Bureau of the Convention on Wetlands (Ramsar 2000), requires the involvement of local and indigenous people in the management of wetlands to ensure their meaningful participation in the decision-making process. This recommendation also recognizes the value of local knowledge and skills in wetland management.

Participatory research methodologies are designed to incorporate local knowledge and involve local people in all stages of research. Increasingly these methods are seen as integral to the success of research efforts and to the local adoption of the resulting recommendations (Brown & Wyckoff-Baird 1992).

In general, however, natural scientists remain sceptical of formally incorporating the knowledge of local people into the application of scientific research methods. Little role exists for 'non-experts' (lay citizens) in deductive approaches to research. Participatory research methodologies are not commonly employed outside the hybrid natural science disciplines (e.g. ethnobotany, human ecology) because understanding human behaviour and assessing local knowledge are not among the principal objectives of natural science research. However, formal inclusion of local knowledge may improve environmental scientific research. Local knowledge of a natural phenomenon may help to define research hypotheses more tightly and may raise locally important (and unimportant) variables, enhancing both the efficiency and the quality of the research effort (Seidl 1996). Moreover, local people may benefit from their inclusion in environmental research on at least two dimensions. First, the policy recommendations resulting from such research are more likely to be accurate, recognized and implemented by local people who have 'bought in' to the research process. Secondly, local people may derive a sense of personal and community pride from helping interested and educated outsiders with their research.

We adapted a participatory research methodology developed in the ethnosciences to incorporate deep local knowledge of a natural phenomenon while maintaining the scientific rigour necessary to draw statistically and empirically relevant solutions. We applied this adapted methodology to a limnological phenomenon known as 'dequada', meaning 'dirty water', in the Brazilian Pantanal wetland. The most noteworthy feature of dequada is the consequent fish mortality (Calheiros & Ferreira 1997; Calheiros & Hamilton 1998). With this study, we aimed to assess the quality of local knowledge of locally observable natural phenomena. We argue for the appropriate employment of this participatory methodology in natural scientific research.

LIMNOLOGICAL STUDY

Covering an area of close to 140 000 km^2, the Brazilian Pantanal is one of the largest freshwater wetlands in the world. The Pantanal is located within the Upper Paraguay River Basin (UPRB) near the geographical centre of South America (Fig. 1). Fish are an important source of protein and income, via commercial fishing and tourism, for the 'Pantaneiros'.

The annual and pluriannual cycles of flooding of the UPRB's dozen rivers are among the region's most important ecological phenomena. Practically all aquatic and terrestrial life within the Pantanal, including that of humans, depends upon the timing and magnitude of the floods. The Pantanal is characterized by a very low rate of declination (Brazil 1979) from east to west (30–50 cm km^{-1}) and an even lower rate from north to south (3–15 cm km^{-1}). Flooding begins between September and December in the north, inundating as much as 70% of the Pantanal (Paiva 1984), and takes about 6 months to pass from Brazilian territory (Carvalho 1986). Significant portions of the Pantanal are submerged from 4 to 8 months each year by water depths varying from a few centimetres to more than 2 m (Brazil 1979, 1992; Paiva 1984).

The interaction between water, land and terrestrial plant species during the flood season provokes a series of transformations in the limnological characteristics of the water courses in the region. These natural changes in water quality, locally named dequada, result from this initial interaction between flood water and previously dry land, which initiates the decomposition of the newly submerged organic material, mostly terrestrial vegetation comprised of grasses. It is characterized by colour changes in the water due to dissolved organic carbon, diminished dissolved oxygen concentration, increased electrical conductivity and increased concentrations of carbon dioxide, methane and nutrients such as nitrogen and phosphorus (Calheiros & Ferreira 1997; Hamilton *et al.* 1997; Calheiros & Hamilton 1998).

Depending on the magnitude of these changes in water quality, massive fish kills of the order of tens of thousands of tons can result due to anoxia and high levels of carbon dioxide. Problems result for both local professional and recreational fishing industries. The dying fish exhibit typical behaviour patterns associated with respiratory stress.

In the limnological study accompanying our participatory research (Fig. 2), two sites were selected from a larger set to illustrate how dequada occurs, and its relationship with Paraguay river water (the source of flood waters) and the lake water (Castle Lake) where the fish kill was observed. Sampling

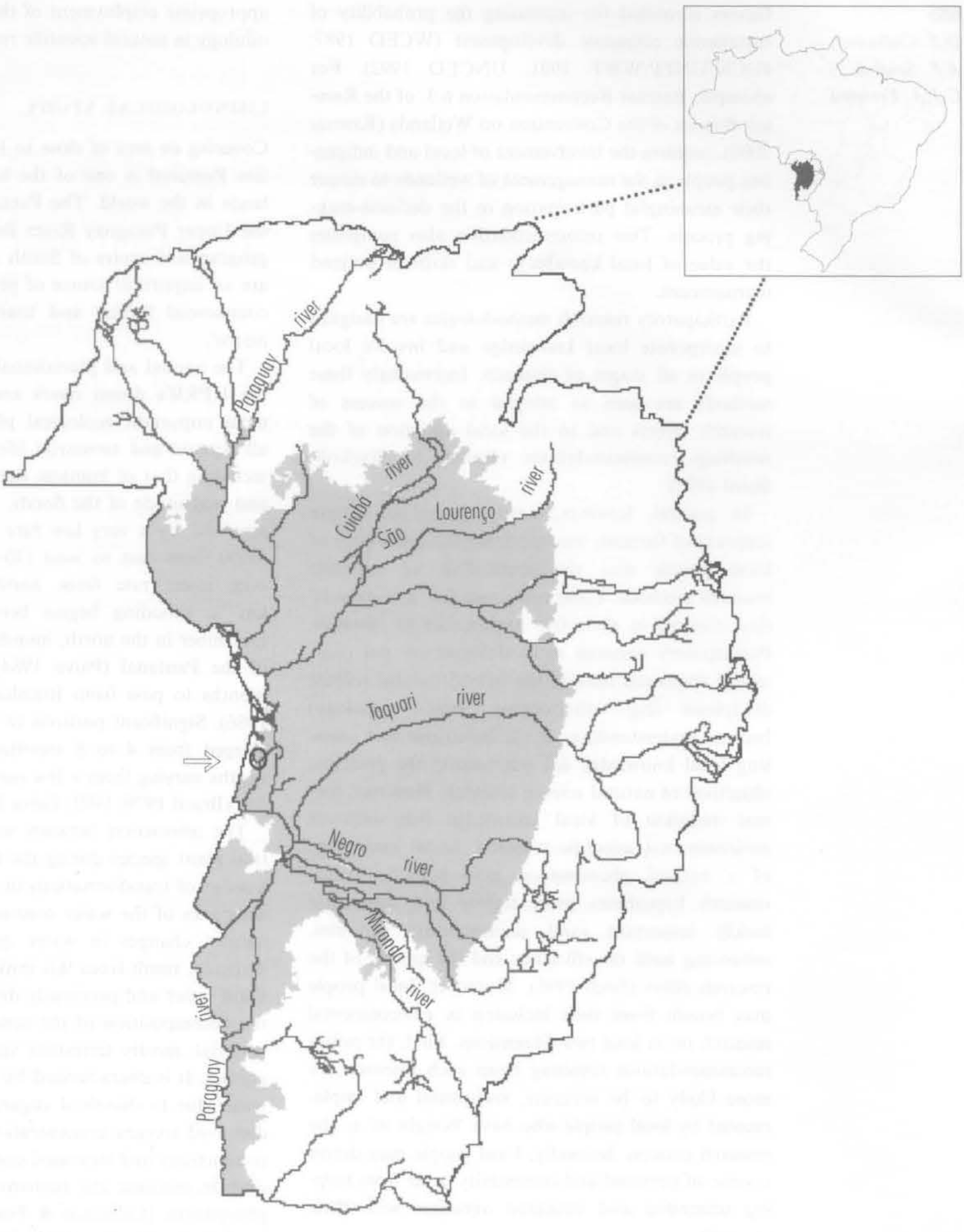

Fig. 1. Localization of Upper Paraguay River Basin (UPRB) and Pantanal wetland (dotted area) in Brazil. The 'Baia do Castelo' (Castle Lake) is indicated with a circle and arrow. Adapted from Silva & Abdon (1998).

spanned the period from low-water conditions (December 1993) through rising water until after the occurrence of the fish kills (August 1994). The sampling interval varied. Profiles of the lake level (corresponding to river level), conductance, dissolved O_2 and free CO_2 are presented in Fig. 2 to show the chemical changes induced by the river's hydrological phases. Alterations in the conductance and concentrations of metabolic gases were observed. The fish kills occurred in the latter part of hydrological phase II, between 1 and 5 June. The methods used to measure the total alkalinity and to calculate the concentration of free CO_2 (from pH, alkalinity and temperature) were from Wetzel & Likens (1991) and Kempe (1982), respectively. The pH values, in general, demonstrated little variation, ranging about 6·25–6·62 in the river and 6·17–6·93 in the lake. The alkalinity changed from 278 to 494 and 315 to 410

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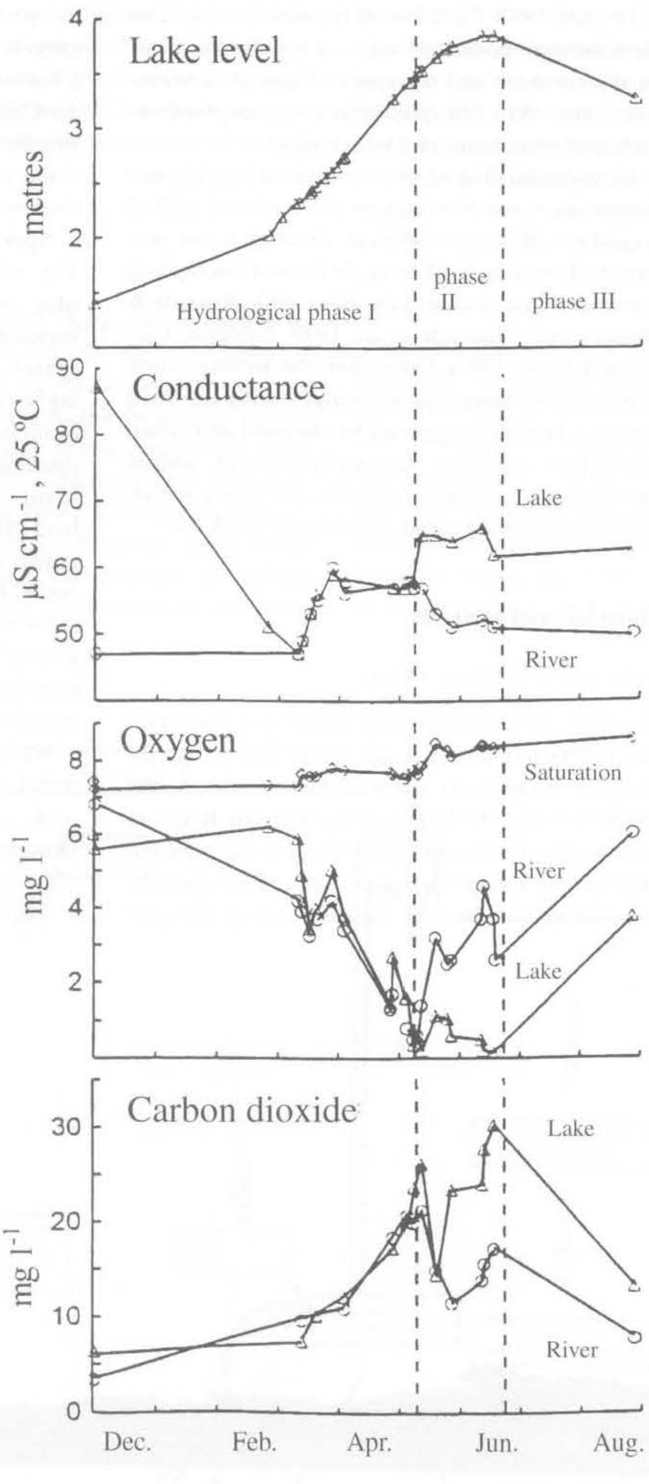

Fig. 2. Water level, conductance and dissolved O_2 and CO_2 in Castle Lake and the nearby Paraguay River, for the December 1993 to August 1994 period. The saturation concentration is given for dissolved O_2. Phase I was the initial rising-water phase; in phase II river water spilled over the levee, passing through extensive previously dry floodplain areas before reaching the lake; and in phase III the water levels gradually fell and the lake and river waters tend to come back to normal conditions. The fish kills occurred in the later part of phase II (Calheiros & Hamilton 1998).

μeq l^{-1}, respectively, in the lake and river; the water temperature ranged from 23 to 33 °C in both systems. Chlorophyll *a* concentrations did not indicate algal blooms (2·2–10·6 μg l^{-1}, in the lake), suggesting that algae were not a factor in the fish kills.

Precise numbers of the dying fish were not available because local fisherman quickly collected them. Massive fish kills of this kind have been observed in the larger rivers of the UPRB (Fig. 1), principally the Cuiabá, Miranda and the Paraguay (Calheiros

& Ferreira 1997; Calheiros & Hamilton 1998). This phenomenon appears to act as a regulatory factor on the structure and dynamics of aquatic communities other than fish (phytoplankton, zooplankton, bacterioplankton and benthic animals).

An understanding of the connections between this phenomenon and fish kills in the Pantanal and of dequada itself was incomplete, although some progress had been made (Ferraz de Lima, Conceição & Ferraz de Lima, undated; Da Silva 1984; Resende & Mourão 1987; Resende *et al.* 1990; Pellegrin, Calheiros & Costa 1995). Other than the decomposition of plants and changes in hydrology during the flood season, it has been suggested by the press and urban people that ash from burning land cover, animal and human waste, agrochemicals, and heavy metals used in gold mining could be causes of fish kills.

Materials and methods

BAÍA DO CASTELO AREA

The Baía do Castelo (Castle Lake) is a floodplain lake (12 800 ha) with a small village located on the Paraguay River to the north of the city of Corumbá (18°34′38″ S, 57°34′ W), near the Bolivian–Brazilian frontier (Fig. 1). The Paraguay River is the principal river of the Upper Paraguay Basin. This location was selected for research because, due to the geomorphological characteristics, the dequada phenomenon is a common occurrence and because there was a human settlement present. The community of Baía do Castelo is representative of the few traditional human colonies within the region in its size, composition and closely integrated relationship with local river systems.

Approximately 30 families live in Baía do Castelo. The village is arranged in a single line along the edge of the lake with a relatively large distance between the houses. It has a small Protestant church, a public primary school, and a hotel catering to fishing tourism. The orientation of the village facilitates access to the water for drinking, cooking, cleaning and fishing for food and recreation (Fig. 3). Many of the homes have small plots of cultivated land. Staples such as manioc, corn and herbs are grown in the household plots, which also support cattle, horses and other domestic animals. Produce is for home consumption and sale at the street markets of Corumbá. Baians participate in the formal economy by working in the recreational fishing industry.

When dequada occurs, the majority of the villagers use rain water, preferring neither to drink, to cook nor to bathe in the waters of river and lake. However, villagers report no adverse effects such as ill-health in themselves or their domestic animals as a result of consuming lake water during dequada.

Fig. 3. The fisherman in the Castle Bay.

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Similarly, people who eat moribund fish captured during this period report no ill effects other than a different taste and texture of some of the more popular fish. Residents choose not to make manioc flour during these periods due to a perceived risk of spoilage.

METHODOLOGY

An ethnographic research design was adopted to recover the information held by the community of Baia do Castelo with regard to dequada and its associated fish kills. The principle behind the ethnographic approach is that people understand their own circumstances better than researchers from outside the area (Gladwin 1989). Ethnographers commonly refer to knowledge of human institutional relationships. We extend the assertion to include human relationships with the natural environment. In order to understand a person's behaviour, it is necessary to understand how she or he perceives reality, her or his alternatives, and the environment (Becker 1970). We argue that these perceptions are helpful in understanding the natural environment.

Research in ethnographic decision-tree modelling employs a two-stage approach: model formation and model testing (Fig. 4). The model formation phase involves an iterative process of definition and redefinition of variables based on the results of structured and semi-structured interviews. The evolving model is adjusted after each interview and subsequent insight. Locally relevant variables, contexts and considerations regarding the phenomenon are identified in the context of the variables raised in previous scientific work. The weight of previous scientific knowledge provides a basis from which to formulate survey questions, interpret responses, and to better understand information provided by the

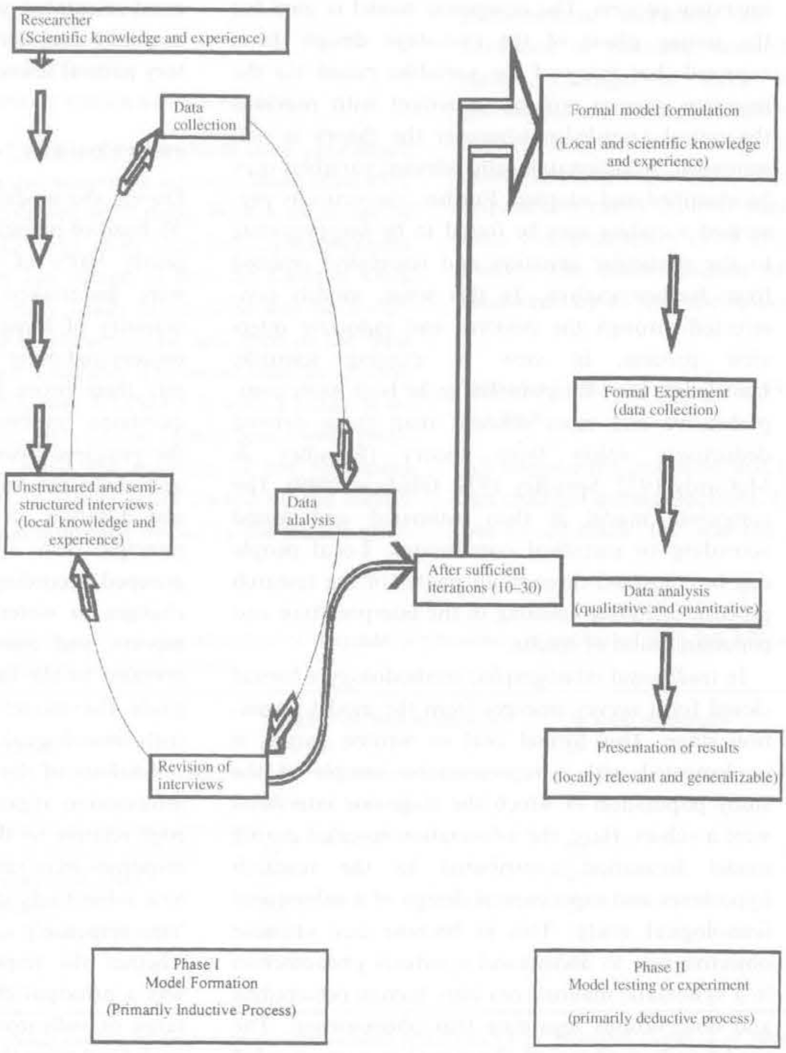

Fig. 4. A research methodology combining local and scientific knowledge. Adapted from Gladwin (1989) and Seidl (1996).

community. Complementary local and scientific knowledge are integrated in order to structure the limnological study of dequada and its effects. Through the iterative model formation stage, scientific research is customized to the specific needs of the research problem. Formal scripts and questionnaires are employed, but open-ended questions and dialogue techniques are used as well. The researcher learns through careful listening, interpreting and conversing with individuals. Studies employing these techniques are more productive than traditional approaches in understanding problems and finding innovative solutions (Soderbaum 1994).

Little additional information is provided to the gradually evolving model after approximately 30 interviews (cf. the central limit theorem). Gladwin (1989) suggests that a definitive model to be used in the testing phase requires a minimum of 10 interviews. The requisite number of interviews depends upon problem complexity and researcher experience (Seidl 1996).

A composite model is constructed from the accumulated information derived from the extensive interview process. The composite model is used for the testing phase of the two-stage design. It is expected that many of the variables raised via the interview process will be consistent with previous theoretical knowledge whenever the theory is well grounded. Additional, locally relevant variables may be identified and adopted. Further, theoretically prescribed variables may be found to be inappropriate to the particular situation and (carefully) omitted from further analysis. In this sense, models constructed through the iterative and inductive interview process, in view of existing scientific knowledge, have the potential to be both more comprehensive and more efficient than those derived deductively solely from theory (Spradley & McCurdy 1972; Spradley 1979; Gladwin 1989). The composite model is then estimated and tested according to statistical conventions. Local people can be consulted through all phases of the research process, including assisting in the interpretation and communication of results.

In traditional ethnographic methodology a formal closed form survey emerges from the model formation stage. This formal oral or written survey is implemented with a representative sample of the study population of which the stage-one interviews were a subset. Here, the information revealed during model formation contributed to the research hypotheses and experimental design of a subsequent limnological study. This is because our ultimate objective was to understand a natural phenomenon in a systematic manner, not only human perceptions and observations regarding that phenomenon. The model testing phase of the research corresponded with the rigorous conventions of limnological scientific inquiry.

The experimental design of this research combined the benefits of deductive and inductive approaches, and of both qualitative and quantitative information. The ethnographic methodology is particularly useful in situations where theory is incomplete, phenomena are observable and important at the local level, and when prediction is among the main objectives of the research (Seidl 1996).

Two principal considerations need to be evaluated in relation to the methodology used in this research: the quality of local knowledge of dequada and its attendant fish mortality; and the impact of incorporating local knowledge of dequada on the quality of environmental research. Two additional considerations become important in social science or policy orientated work: whether the participation of local people in environmental research improves the management of the environment at the local level; and whether their inclusion enhances their sense of worth, empowerment, stewardship, community, etc. Here, we only address the first set of considerations. The second set is widely held as an outcome of economic development and natural resource management-orientated social science research, but is not normally considered a planned output of participatory natural science research.

PROCEDURES

During the model formation stage of this research, 30 head-of-household oral interviews, representing nearly 100% of the families of Baía do Castelo, were undertaken by the same interviewer. The majority of those interviewed were small property owners and older men who had lived in the community their entire lives. Using primarily open-ended questions, respondents were asked their opinions of the principal causes and characteristics of dequada and of the fish kills, the timing, location, magnitude and duration of the phenomenon, as well as the principal fish species affected. Responses were grouped according to potential causes of fish kills, changes in water characteristics and hydrological aspects, and changes in fish behaviour. Variables revealed in the interviews were used to define and guide the model testing, experimental design, or truly limnological stage of the research.

Analysis of the 30 stage-one interviews provided information regarding the quality of local knowledge relative to the scientific community. Interview responses were ranked as categorical data according to a subjectively determined ordinal scale (4, 2, 0 or 'no response'). The assigned values represent whether the respondent indicated that the factor was a principal cause or indicator (4), a secondary cause or indicator (2), not a cause or indicator (0), or did not raise the factor in any way in response to open-ended questions. An approximate t-test for differing observations and variances was used to distin-

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guish statistically the mean values of responses (Ott 1988). Results were analysed comparing local information with the results of this limnological study and with previous scientific information.

Using this methodology in a small community, 'learning' among later interviewees from the interview experiences of earlier subjects is a real possibility. To investigate whether responses demonstrated trends due to the interview sequence, we estimated response similarities among questionnaires using the Bray–Curtis (Czekanowski) index (Bray & Curtis 1957). This index is appropriate because it is not affected by joint absences (Belbin 1995) and is less affected by aliasing than most similar indices (MacNally 1994). We used semi-strong multidimensional scaling (MDS; Belbin 1995) to reduce the variable 'responses' to one dimension. To test if the sequence of the applied questionnaires would decrease response variability, we calculated the difference of variances of the first and last third part of the resulting MDS axis and compared them with the differences obtained via Monte Carlo simulation (1000 random runs).

Results

DEMOGRAPHIC CHARACTERISTICS

Approximately 90% of respondents cited agriculture as their principal economic activity. More than 93% of those interviewed were male. With a mean age of 55·3 years (SD 13·9), more than 75% of respondents were born in the village of Baía do Castelo. Only one of the family heads interviewed was born outside the UPRB. However, he had lived in the Baia for more than a decade. The mean number of children per family was 4·7 (SD 3·7) with a range of 0–15. More than 40% of the family heads were property owners, while the majority of the remaining 60% worked on family lands owned by the former 40%. The total land area owned by the Baians interviewed was 3090 ha, or 107 ha per family (SD 285·5), with a range of 0–1440 ha. Even the largest of these properties was considered quite small within the Pantanal region, which has a farm average area of 10 000 ha (Silva & Abdon 1998).

IDENTIFICATION OF THE PHENOMENON

The limnological phenomenon known as dequada is frequently confused with its most evident effect: massive fish kills. However, all Baians correctly identified it as 'strong' or 'bad' water and all recognized that fish kills were events strongly correlated with the occurrence of this phenomenon. Originally, the name 'diquada water' refers to ash-red coloured water used in the home production of bars of soap, similar in colour to the rivers and lakes when the phenomenon is occurring.

CAUSES OF DEQUADA

In open-ended questions, 30 interviews identified six potential causes and observed characteristics of the phenomenon, including all of those variables advanced in scientific research except for heavy metals. Changes in water levels or directions, decomposition of organic materials, and ash from burning land cover were the most commonly cited causes/characteristics of dequada (97% of all respondents each). Animal waste and agrochemicals were less commonly cited (10% and 3%, respectively). The decomposition of poison plants was mentioned by 13% of the respondents (Table 1).

INDICATORS OF DEQUADA: CHANGES IN WATER

All respondents indicated that the water characteristics changed during dequada. Changes in water colour to red-black 'tea' was the most evident sign of

Table 1. Potential causes and characteristics of dequada, a phenomenon associated with fish kills in the Pantanal wetland (Brazil) as revealed by local respondents

Characteristic/cause	Number of respondents (n) ($N = 30$)	% total responses (n/N)	Mean assigned value* ($\Sigma i/n$)
Hydrology (changes in water level, volume, direction)	29	97	4·00 [a]
Decomposition of organic materials	29	97	3·79 [b]
Ash from burning land cover	29	97	2·70 [c]
Depletion of oxygen	8	27	4·00 [a]
Decomposition of poison plants	4	13	2·50 [c,d]
Animal waste	3	10	2·00 [d]
Agrochemicals	1	3	2·00 [d]

*Subjective ordinal coding of responses to open-ended questions (4 = principal cause, 2 = secondary cause, 0 = not a cause). 'No response' was neither scored nor included in mean scores.[a,b,c,d] indicates statistically distinct responses obtained via approximate t-test considering differing numbers of observations and variances at 95% confidence where d.f. $= n_1 + n_2 - 2$.

Table 2. Indicators of dequada: observed changes in the water, identified from local knowledge and previous scientific studies

Characteristic	Previous scientific knowledge	Local knowledge (%)*
Changes in colour	Yes	100
Changes in odour	Yes	93
Changes in taste	No	60
Presence of foam	Yes	57
Presence of shiny film or oil	Yes	53

* Percentage of affirmative responses to an open-ended question ($N = 30$).

the initiation of the phenomenon recalled by those interviewed. Changes in water odour and taste were commonly cited (93% and 60% of respondents, respectively), as were the appearance of foam and an oily film on the water's surface (64% and 53%, respectively). Other than changes in taste (apparently no scientists thought to measure this dimension), the indicators most commonly cited by Baians coincided with scientific information on the phenomenon (Table 2).

Four locations where dequada might be observed were cited: lakes (100%), rivers (97%), permanent canals (77%) and seasonal flood courses (17%) between rivers and lakes (Table 3). The genesis of the fish kills associated with dequada was thought to be in the floodplain, filled by river flood waters that have passed from the river levee over formerly dry lands, by 47% of respondents. Both the speed and extent of flooding were considered important to the occurrence and severity of the fish kills associated with dequada (33%). A few respondents (7%) indicated that fish kills were more severe during periods of dequada following a prolonged dry season. Subsequent testing supported each of these hypotheses (Calheiros & Ferreira 1997; Calheiros & Hamilton 1998).

A reverse in the direction of water flow between the river and the lake was observed by a few respondents (7%) as an indicator of the beginning of a dequada period. In this particular system, after river water spills over the levee up-river from the lake

Table 3. Locations where dequada was observed according to interviews with local people

Location	Affirmative response (%)*
Lakes	100
Rivers	97
Permanent canals ('corixos')	77
Seasonal water courses ('vazantes')	17

*Responses to an open-ended question ($N = 30$).

entrance, it passes through extensive floodplain areas before reaching the lake, and forces lake water to exit back to the river through the connecting channel.

Again, subsequent observations supported both the occurrence and the importance of the reverse water flow to dequada occurrence (Calheiros & Ferreira 1997; Calheiros & Hamilton 1998).

INDICATORS OF DEQUADA: CHANGES IN FISH BEHAVIOUR

All Baians interviewed cited specific changes in the behaviour of fish as another indicator of the initiation of a period of dequada. Of the nine distinct behavioural differences cited, the three most commonly cited changes in fish behaviour during the phenomenon include 'breathing' at the surface of the water (100%), swelling in the lips of certain fish species (93%), and that the fish seem to become stupid, slow or easy to catch by hand (57%). These changes in fish behaviour cited by residents were in concordance with scientific information. However, residents also indicated that fish tend to jump out of the water, float, lose their equilibrium, or become difficult to catch by fishing with bait (Table 4), changes in behaviour not identified in previous studies.

Baians were able to indicate which species were most affected and the relative magnitude of the effect. More than 90% of respondents indicated that all species of fish were affected. Using the common names provided in interviews it was possible to identify 25 species representing 12 families affected by fish kills: Pimelodidae, Characidae, Prochilodontidae, Sciaenidae, Erythrinidae, Anostomidae, Gymnotidae, Pristigasteridae, Potamotrygonidae, Ageneiosidae, Achiridae and Cynodontidae.

One species, called 'Corredeira' (*Auchenipterus nuchalis*), was cited by 10% of respondents as an indicator of the onset of dequada. It is mostly seen at this time and is never fished. The scientific community was unaware of this indicator species previous to this study.

PRINCIPAL CAUSES OF FISH KILLS

The probable causes of fish mortality identified in the surveys were analysed to determine whether they were generally considered 'principal causes', 'secondary causes' or 'not a cause' by the community. In statistical tests residents identified four distinct strengths of responses to the perceived causes of dequada. Changes in hydrological features ($n = 29$, $\mu = 4{\cdot}00$) and the depletion of oxygen ($n = 8$, $\mu = 4{\cdot}00$) were statistically distinct from decomposition ($n = 29$, $\mu = 3{\cdot}79$) as the three principal causes of fish mortality during periods of dequada (d.f.$_1 = 56$, d.f.$_2 = 35$, $P < 0{\cdot}05$). Statistically distinct from

Table 4. Indicators of dequada: observed changes in fish behaviour identified from local knowledge and previous scientific studies

Observed change	Previous scientific knowledge	Local knowledge (%)*
'Breathe' at the water's surface	Yes	100
Swollen 'lips' on some species	Yes	93
Become 'stupid' (slow, easy to catch by hand)	Yes	57
Some species move from the channel to the river's edge	No	30
Jump onto the river bank	No	20
Don't eat (difficult to catch with bait)	No	13
Float and lose their equilibrium	No	10
Appearance of the species 'Corredeira'	No	10
Diminish in number	No	3

* Percentage of affirmative responses to an open-ended question ($N=30$).

decomposition and equivalent to secondary causes of fish mortality were ash from burning land cover ($n=29$, $\mu=2{\cdot}70$, d.f. $=56$, $P<0{\cdot}05$) and toxic plants ($n=4$, $\mu=2{\cdot}50$, d.f. $=31$, $P<0{\cdot}05$). Finally, animal waste ($n=3$, $\mu=2{\cdot}00$) and agrochemicals ($n=1$, $\mu=2{\cdot}00$) were viewed as having the least potential as a cause of fish mortality during periods of dequada in the opinion of the residents of Baía do Castelo. These mean responses were statistically distinct (lower) from ash (d.f.$_1=30$, d.f.$_2=28$, $P<0{\cdot}05$), but statistically equivalent to the decomposition of plants (d.f.$_1=5$, d.f.$_2=3$, $P>0{\cdot}05$) (Table 1). Baians' opinions of the principal causes of dequada and its associated fish kills were largely upheld in subsequent tests (Calheiros & Ferreira 1997; Calheiros & Hamilton 1998).

TIMING AND DURATION OF FISH MORTALITY

In accordance with accepted scientific information, all respondents agreed that fish kills occurred while flood waters were increasing rather than in periods of receding waters. In addition, and providing information for a research hypothesis, 53% of respondents indicated that the magnitude of fish mortality followed the flood cycle; strong flood following a year of extended dry season brought on greater fish kills.

The approximate duration of fish kills during dequada, and of dequada itself, was unknown prior to this study. Baians indicated that periods of dequada lasted from 15 days to 2 months, with 43% indicating 1 month as typical. Fish were said to die-off for from 1 day to about 1 week during periods of dequada, with 43% indicating that the fish kills were typically 2–3 days in duration.

TEMPORAL TRENDS IN RESPONSES

To estimate whether responses demonstrated trends due to the interview sequence, we obtained observed variances correspondent to 1·912 and 0·467 for the first and the third questionnaire groups (Fig. 5), respectively, and the observed difference was 1·445. In 1000 random simulations (Monte Carlo procedure), 136 results were higher or equal to the observed difference, the probability of which was $P=0{\cdot}136$.

Discussion

These results indicate that the residents of Baía do Castelo possess a great deal of accurate information regarding the observable aspects of this limnological and associated biological phenomenon. In the majority of cases, local knowledge agreed with general scientific information about the phenomenon. In many instances, interviews revealed useful new

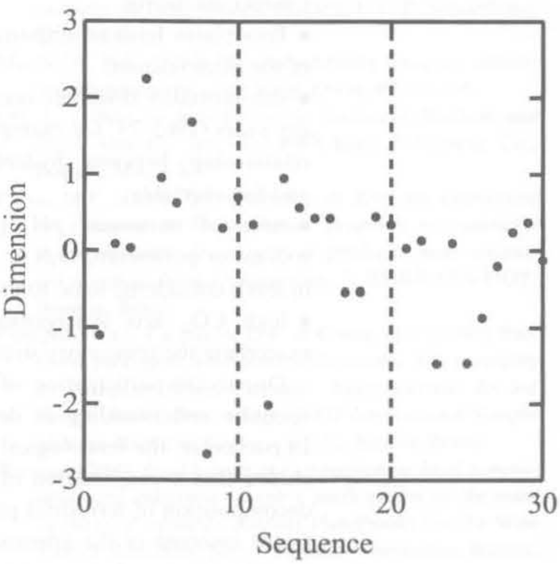

Fig. 5. Result of multidimensional scaling (MDS) procedure to reduce the variable 'responses' to one dimension regarding the interview sequence. The dashed lines represent the three questionnaire groups.

information about dequada and associated fish mortality in the Pantanal wetland. Using the local community knowledge in conjunction with the results of traditional scientific research, it was possible to design a superior limnological research effort.

While this hybrid methodology proved useful and effective in our research effort, we would be remiss if we failed to mention its shortcomings. Population surveys conducted by personal interview are time consuming and can be expensive. Bias can also be introduced through the use of multiple interviewers. The evaluation of population survey information is often couched in terms of mean responses. This information, while representative of the community's perceptions, may be neither accurate nor innovative. It may be more appropriate to seek out 'expert' information from a community rather than 'average' information in attempting to reveal new insights about a scientific phenomenon. The use of a stratified 'snow ball' sampling technique is one way in which to address such a criticism (Gladwin 1989). These issues should be taken into account in the design of future research projects using these hybrid techniques.

In addition, learning among interviewees can take place over the course of the research process thereby biasing information gleaned from later interviews. Although the variance decreased along the MDS axis (Fig. 5), our results ($P = 0{\cdot}136$) demonstrated that we could not reject the null hypothesis that questionnaire sequence had no influence on responses.

Hypotheses raised in previous work (Ferraz de Lima, Conceição & Ferraz de Lima, undated; Da Silva 1984; Resende *et al.* 1990; Calheiros *et al.* 1991) were supported through the study of Baía do Castelo, including:

- floodplains have an important role in the genesis of the phenomenon;
- fish mortality does not occur due to dequada in dry years (1963–73, for example), demonstrating the relationship between hydrological characteristics and fish mortality;
- none of ammonia, pH, phytoplankton toxins, sodium or potassium, H_2S or aluminium was found in levels considered toxic to fish;
- high CO_2 acts synergistically with low O_2 to exacerbate the respiratory stress on fish.

Due to the participation of the local community, scientific understanding of dequada was advanced. In particular, the limnological researchers have concluded that a combination of flood waters and the decomposition of terrestrial plants is the most likely factor involved in the alterations of respiratory gas concentrations and, consequently, the local fish die-off. The decomposition process diminishes the available oxygen in the water and increases the carbon dioxide concentrations. Conditions of low levels of available oxygen in tandem with elevated levels of carbon dioxide exacerbate the respiratory stress of the fish and result in their asphyxiation. Critical levels of less than $1\,mg\,l^{-1}$ for oxygen in conjunction with greater than $20\,mg\,l^{-1}$ for carbon dioxide were identified as the threshold for fish kills in this system (Calheiros & Ferreira 1997; Calheiros & Hamilton 1998).

Several tentative policy inferences may be made from this case study. It does not appear likely that land clearing practices or mining and agricultural operations are influencing fish mortality in the Upper Paraguay River Basin. Complementary research is required to understand these influences on fish populations closer to the sources of heavy metals and agrochemicals. Dequada may occur in the spawning and hatching times, as well as in the larval period. As a result, commercial fish farming ventures should probably be located nearer to the headwaters of the principal rivers, in rivers at lesser flood risk within the region or in other periods.

In order to share the importance of this research with the local community, the interviews were preceded by an explanation of why an understanding of the functioning of the system can help its conservation. The value of local knowledge about the system was emphasized. In addition, the first paper produced was distributed to some of the families that were interviewed, illustrating the results and demonstrating the importance of their participation in the effort. Researchers continue to conduct studies in the locale.

Conclusions

In the Pantanal, few environmental researchers hail from the region and only a handful have a decade of experience there. Scientific literature concerning the Pantanal is practically non-existent prior to 1975. The vastness, uniqueness and difficult logistics of the Pantanal combine to provide significant hurdles to undertaking scientific study, but also create great opportunities for investigation. The knowledge of local natural processes that 'Pantaneiros' have developed over the generations is substantial. An adapted ethnographic research design provides a systematic way in which a linkage between these two kinds of understanding is possible.

The residents of Baía do Castelo maintain a great store of knowledge regarding the causes, indicators and observable impacts of dequada in their community. In a number of cases, in particular fish behaviour, location of the phenomenon, and the most commonly affected fish species, local knowledge was found to be superior to that of the scientific community. The incorporation of local knowledge improved the performance of the limnological research on quality and efficiency dimensions by corroborating the importance of some theoretically prescribed variables, eliminating others, and in raising new dimensions for research consideration. The methodology facilitated the discovery of locally important variables and significant contextual complexities, the absence of which would have increased the likelihood of erroneous interpretation of results.

It is believed that the community is more likely to accept policy recommendations stemming from this research due to their participation. We suggest that there is a role for the exploration of this and other participatory approaches in environmental scientific research in the future.

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