Australian Government
Department of the Environment and Heritage
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internal report 470

A review of options for monitoring freshwater fish biodiversity in the Darwin Harbour catchment

Report prepared for Water Monitoring Branch, Natural Resource Management Division, Department of Infrastructure, Planning & Environment

R Pidgeon

January 2004

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Registry File SG2003/0055

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1 Background

Darwin Harbour and surrounding rural and urban areas of its catchment are presently undergoing an increase in infrastructure development and proposals for more developments are inevitable. The Northern Territory Government has instigated initiatives to develop effective environmental protection strategies as part of a strategic development and management plan for the harbour. An important component of this strategy is a comprehensive environmental monitoring program. This report provides advice on options for including the monitoring of freshwater fish in the waterways of the harbour catchment in the existing suite of biological, physical and chemical environmental monitoring programs being undertaken by the Department of Infrastructure, Planning and Environment. (Darwin Harbour Advisory Committee 2003).

Fish are an important component of aquatic ecosystems through their role as consumers of other organisms and they can have a significant influence on the structure and function of these ecosystems. Because of this, adverse effects on fish can have adverse flow–on effects on other aquatic organisms even if they are not directly affected by those changes in water quality. Monitoring of fish communities can, therefore, provide a useful indicator of the ecological health of natural waters.

Fish are sensitive to many changes in water quality and habitat structure caused by human activities and by natural causes. Common adverse anthropogenic effects on fish can result from many factors including: contamination of water by waste metal pollution, pesticides, salinity and organic wastes and nutrients causing either direct effects on fish health or indirect effects on the oxygen climate in the water through eutrophication; and physical habitat changes such as thermal pollution, changes in stream flow regime, stream bed aggradation, de-snagging, and land clearance, especially in riparian zones. Consequently, as well as their intrinsic biodiversity value and the human food value of some species, fish can be useful indicators of the impact of many different human activities on the environmental health of a waterbody.

The use of fish community structure in environmental monitoring programs of freshwater systems (as opposed to fishery management programs) has increased in recent years. This is due in part to increasing public concerns about loss of natural biodiversity resulting from human activities and the higher public profile of fish in comparison to smaller invertebrates that are more widely used in assessment of the health of stream ecosystems. Also, as well as concern for the health of fish and the aquatic environment, there is often concern about the risk to humans from the consumption of fish from contaminated waters.

However, the use of fish in environmental monitoring has not been widespread in the NT. The most extensive environmental monitoring of freshwater fish in the Northern Territory has been in the Magela Creek and South Alligator River in relation to Ranger Uranium Mine

(Humphrey and Pidgeon 1995). and in the Finnis River system in relation to Rum Jungle uranium mine (Jeffree 2002; Twining 2002). There has, however, been considerable research on the ecology and taxonomy of freshwater fish in the NT (Bishop et al 1984, 1990, 2001; Larson and Martin 1989). The taxonomy and basic biology of NT freshwater fish is now sufficiently well known to provide a good basis for monitoring programs. Nevertheless, new species are still being discovered and future biochemical genetics studies are likely to show up more species or subspecies. Fisheries research in freshwater in the NT has focused almost entirely on management of one species, barramundi (*Lates calcarifer*) rather than biodiversity issues.

2 Advantages and disadvantages of monitoring fish

Advantages

Compared to invertebrates and algae there are relatively few fish species to be considered in biodiversity measures in freshwater, especially in Australia. Although some species are difficult, or impossible, to distinguish in the field, most species are relatively easy to identify. This makes collection of data on numbers of fish of different species quite rapid once the fish have been captured. Training of staff to identify fish is relatively easy with only about thirty species likely to occur at any one location (usually much less) and around fifty species possible in an entire catchment in the Top End.

There is little difficulty in identifying larger individuals of most species. However, the juveniles and smaller sizes of some species groups can be difficult to separate. This can be a problem when a number of these species are known to occur in the one river system. The main groups where this problem occurs are the eel-tailed catfish (*Neosiluris* and *Porochilus* spp) and some rainbowfish (*Melanotaenia splendida* sub spp, *M. australis and M. solata)*

Fish are useful where there are known potential contaminants of concern for human or ecological health reasons. The large body size of many fish makes them convenient for taking tissue samples for measuring levels of contaminants in fish.

Disadvantages

The mobility of fish is a major disadvantage for monitoring programs since unless there are barriers to fish movement, different sites on a river system cannot be strictly regarded as independent. In Top End rivers there is extensive dispersal of fish along river channels and across wetlands during the wet season (Bishop & Forbes 1991; Bishop et al. 1994). This makes it invalid to use sites upstream from a known point source of pollution as a control site for changes that may occur downstream. Control sites then should ideally be on different stream systems.

The mobility of fish also makes them difficult to sample and many different capture techniques have been devised for different habitats and types of fish behaviour. Unfortunately, each capture method has its own bias towards certain species and sizes of fish making this aspect an important consideration in the design of monitoring programs and interpretation of results.

The gregarious behaviour of many schooling fish species can also be a problem for sampling by increasing the likelihood of not detecting the presence of that species when sampling is conducted over a short time period or on a limited spatial scale.

Adverse environmental effects on fish can sometimes be spectacular when the sudden death of most or all fish in a stretch of water occurs at one time. Unfortunately, this can result from a number of natural causes (Bishop et al. 1982; Noller & Cusbert 1985; Townsend 1994) as well as effects of human activities. Consequently, when such incidents occur downstream from a potential human source of disturbance it is necessary to determine whether natural or human causes were involved to enable regulators to advise business operators on suitable management actions.

3 Design considerations for a fish monitoring program

There are many factors that must be considered in designing any environmental monitoring program (Fig. 1). The design of a fish monitoring program is very much dependant on the management objectives and the parameters to be measured. For the objective of environmental protection the common parameters used are measures of biodiversity and measures of levels of contaminants of interest in fish tissues. Various indicators of fish health can also be measured. In some situations toxicity studies of water on fish (and other organisms) may be particularly useful, especially where adverse effects of known contaminants cannot be predicted and where chemical monitoring cannot explain observed adverse biological effects.

Where there are species of conservation significance, population studies similar to those used by fisheries managers may be warranted. However, for the Darwin Harbour catchment the absence of any rare and endangered species in present museum records (Table 1) makes that approach unnecessary at this stage. The present review focuses on biodiversity assessment and also considers some of the procedures that might be used for measurement of bioaccumulation of contaminants.

Preliminary literature and field pilot studies should be undertaken to provide information on the following:

1. Risk assessment of potential environmental impacts to decide on habitats and locations of concern, if any.
2. The array of fish species likely to be encountered

The risk assessment allows the decisions on what habitats and number of stream or wetland locations are required to test hypotheses involved in achieving management objectives.

The information on the possible fish assemblage allows the determination of the following:

1. Behaviour of different fish species to determine likely habitats and times to sample for them.
2. Appropriate sampling methods must then be selected considering their effectiveness in different habitats, biases for fish species and sizes, cost, time and effort involved in their use, OH&S issues and training.
3. The time and frequency of sampling taking staff resources and the seasonal behaviour of the fish into account.

The final experimental design will consider these parameters in a model that can test the hypotheses posed. Power analysis can be used to evaluate the level of effects that can be detected by the model.

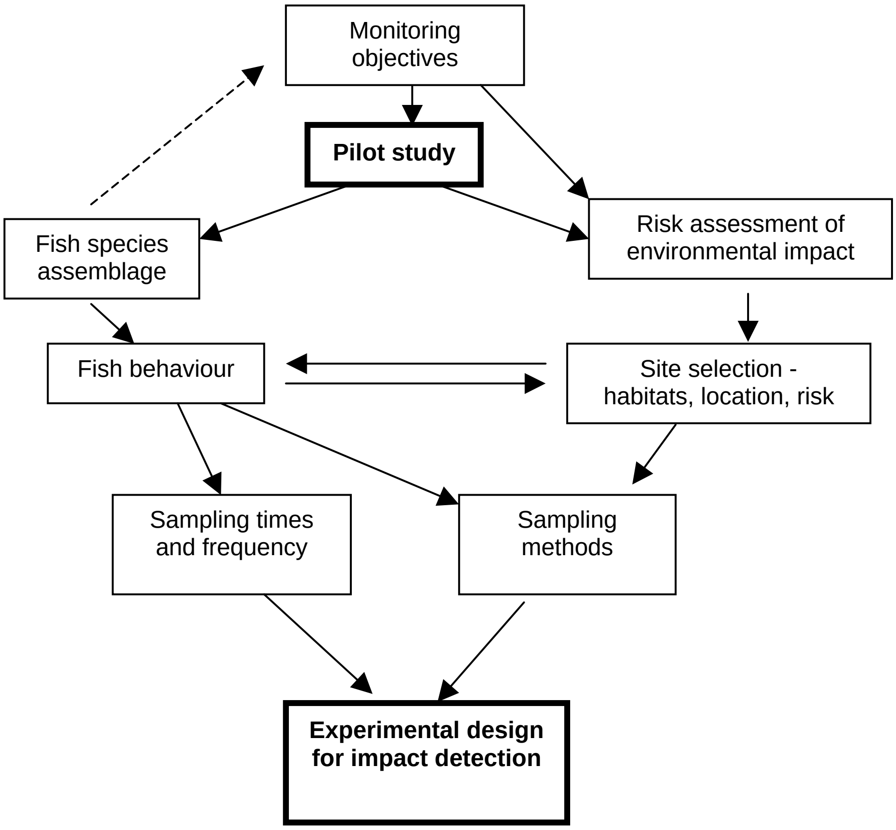


Figure 1 Decision web for designing a fish monitoring program

3.1 Monitoring objectives of a fish monitoring program

In contrast to the estuarine and marine waters of Darwin harbour, the freshwaters of the harbour catchment are not a significant fishery for recreational anglers. Consequently, the management goal of a fish monitoring program would be environmental protection and not fishery management. Nevertheless, the larger streams do provide habitat for immature barramundi (*Lates calcarifer*) and tarpon (*Megalops cyprinoides*) which migrate to marine waters when mature. This input no doubt contributes significantly to the harbour fishery for these species.

The three main objectives of an environmental monitoring program are likely to be biodiversity conservation, maintenance of ecosystem health and protection of human health. Biodiversity and ecosystem health are most readily assessed using fish community structure indicators and population assessment of any species of conservation significance. The latter is not an issue at present as there are, as yet, no species recorded that are listed as rare or endangered. Fish community studies can detect changes in biodiversity indicating loss of species, decline in species richness, and decline in abundance. Change in community structure indices (based on relative abundance of species) can also be useful in detecting adverse effects for assessment of ecosystem health.

Measures of fish health can also be useful indicators of ecosystem health. Changes in external disease indicators and fish condition factors are readily measured.

Table 1 Fish species in freshwaters of Darwin Harbour catchment in records of NT Museum and Art Gallery.

Freshwater species	Catadromous or estuarine vagrants	Feral species
Ambassis agrammus		*Gambusia holbrooki*
A. mulleri	**Catadromous species**	*Osphronemus goramy*
A. macleayi	*Lates calcarifer*	*Poecilia reticulata*
Denariusa bandata	*Megalops cyprinoides*	*Xiphophorus sp*
Craterocephalus stercusmuscarum		*Hemichromis bimaculatus*
Amniataba percoides	**Marine vagrants**	
*Leiopotherapon unicolor**	*Elops hawaiiensis*	
Hypseleotris compressa	*Hemigobius hoevenii*	
Mogurnda mogurnda	*Mugilogobius filifer*	
Oxyeleotris lineolata	*Mugilogobius wilsoni*	
Oxyeleotris selheimi	*Prionobutis microps*	
Oxyeleotris nullipora	*Pseudogobius* sp2	
Melanotaenia splendida inornata	*Pseudomugil cyanodorsalis*	
*M. splendida australis***	*Redigobius chrysoma*	
M. nigrans	*Scatophagus argus*	
Pseudomugil tenellus	*Selenotoca multifasciata*	
Pseudomugil gertrudae		
Strongylura krefftii		
Toxotes chatareus		
Nematalosa erebi		
Neosiluris hyrtlii		
Neosiluris ater		
Ophisternon gutterale		
Glossamia aprion		
Glossogobius giuris		
25 species	**12 species**	**5 species**

* Another grunter species , *Hephaestus fuliginosus* (sooty grunter), has since been recorded by DIPE staff in the Darwin River.

** Another rainbowfish fitting the description by Allen et al (2000) of *Melanotaenia solata* has been recorded in the Howard River system.

Bioaccumulation

Fish may be useful in human health protection by monitoring of levels of contaminants (pesticides, toxic metals and others) in tissues of fish likely to be eaten by humans. These are generally larger fish species and may require a separate sampling program designed for that purpose. The chemical analysis for this approach is very expensive. Consequently, strategies for minimising costs should be based on risk assessment and pilot studies of fish community sampling. A regular monitoring program may not be appropriate at this stage but collection of baseline information of present contaminant levels may be prudent for investigation of any incidents in the future. This might involve the analysis of the livers and flesh of a couple of larger growing species (for ease of dissection) that occur in most streams in the catchment.

3.2 Risk of environmental impact

Threats to fish in the Darwin Harbour catchment may arise from 3 major sources:

1. Water pollution from urban, industrial and agricultural wastes,

2. Habitat modification and loss, and
3. Changes in hydrological patterns from water abstraction and land clearing.

The first two are most likely to have already had some impact on fish communities in small urban streams.

One simplistic way of applying a risk assessment approach is to assume that the level of risk of impact on fish is related to the extent of industrial and urban development and hence, the proximity to Darwin and Palmerston. For planning purposes this can be used to classify waterbodies into risk categories that can be used as different treatment levels in the experimental design of a monitoring program. Four levels are suggested in Table 2.

Whether this scheme is appropriate or not would be determined from more detailed knowledge of the existing and proposed developments in each catchment and the water quality and habitats present in the waterways. This knowledge would help in the identification of any potential point sources of impacts for consideration in the experimental design. Nevertheless, it will be important to identify any potential control streams that could be used in any design for a long term monitoring program. The low risk streams may be suitable for that purpose.

Table 2 Proposed risk level classification of different streams in the Darwin harbour catchment

Risk level		Locations
4	Very high risk	Darwin/Palmerston urban industrial streams and wetlands
3	Moderate-high risk	Inner rural areas – Howard river and Elizabeth river
2	Moderate–low risk	Outer rural areas – Darwin River and Blackmore River
1	Low risk	Remote rural areas – Small streams on Cox Peninsula, Gunn Point Peninsula, and Charlotte and Annie Rivers (Bynoe Harbour)

3.3 Monitoring locations

The Darwin Harbour catchment contains three major types of freshwater bodies that are sufficiently different in structure to expect that their fish communities would also differ. There are four *medium sized river systems* that enter the harbour: Blackmore River and Darwin River enter Middle arm, Elizabeth River enters East arm and Howard River enters Fog Bay (Fig. 2). Of these rivers only the Howard River connects to an extensive coastal wetland system in the wet season and the Darwin River is the only perennial stream fed by a small discharge from Darwin River Dam. There are also a number of *small seasonal creeks* that discharge directly into the harbour. The streams within the urban areas of Darwin and Palmerston are of that type and there are some others on the Cox Peninsula and Gunn Point Peninsula. There are many *lagoons*, especially in the Howard River catchment and these vary in the degree to which they dry out during the dry season. There are also large areas of more ephemeral wetlands that would be difficult to monitor in a predictable manner.

Within each of these categories there are different habitats that influence the fish species composition. The major habitat features influencing fish are water depth, current, density of woody debris and aquatic vegetation. Where the intention is to maximise the capture of as large a proportion of species present as possible, the sampling should include the range of habitats present at a site. In deep pools of streams this would include the deep open water zone and the margins, both shallow and deep, with associated vegetation, woody debris and rocky substrates. In flowing streams shallow riffles and runs should be sampled as some species aggregate in the faster currents present in these areas. In lagoons both the open water zone and densely vegetated littoral zone should be sampled.

These habitat features also affect the performance of different sampling methods. Consequently, different habitats may require sampling by different methods. Recording of habitat parameters and sample method may be necessary for later analysis, especially where comparison of different sites is involved. These data on habitat parameters can also be useful as covariates for distinguishing natural and anthropogenic causes of change in fish communities.

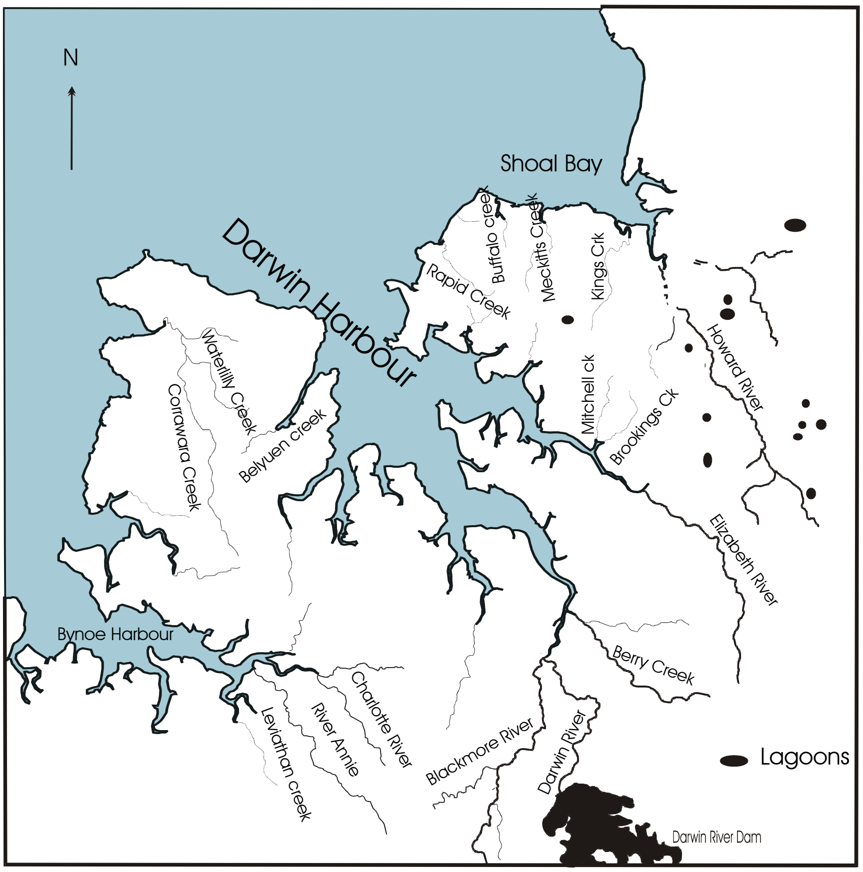


Figure 2 Freshwater streams and wetlands of Darwin Harbour catchment

3.4 Impact detection and site selection

Selection of sites along a water system is usually strategic in relation to the location of known or potential threats. Sites should at least be downstream from potential threats and additional sites upstream of the threats may be useful. However, as mentioned above, upstream sites on a stream may not be considered as valid control sites because of the ability of fish to disperse in both directions through the river system. Nevertheless, inclusion of control sites on separate streams if possible is very beneficial. Site selection may also depend on the proposed method of impact detection. A number of detection approaches may be applied. These include:

- **Control chart** approach – measurements plotted in time series against acceptable levels of change. This is useful for monitoring contaminant levels and some univariate community parameters.
- **Indicator species** approach – Indices based on known sensitivities of different fish species – Similar to the Ausrivas procedure for invertebrates (Simpson et al 1997) and IBI (Harris & Silveria 1999). Not well developed in Australia for fish
- **Change in community indices**, preferably in comparison to reference (control) sites. BACI (Green 1989) and BACIP (Stewart-Oaten et al. 1986; Underwood 1992) designs are recommended wherever possible.

Power analysis of designs after initial sampling help to refine sampling effort and may improve ability to detect change

The **BACIP** (**B**efore – **A**fter **-** **C**ontrol –**I**mpact-**P**aired difference) experimental design is based on the recognition that there will always be some difference between any two sites. It assumes that, in the absence of human impacts, this difference (**P**aired difference) should remain relatively constant, as the biotic community at both sites should change in same way in relation to the same natural variation in environmental parameters. This can be used with univariate and multivariate parameters (Faith et al 1991) to detect significant changes by ANOVA. The paired difference value is analogous to the multivariate similarity value of two communities often calculated in studies of community structure.

Where they can be applied, these designs provide the most effective approach to detecting impacts. However, whilst it often difficult to find appropriate control streams, in practice it usually impossible to get Before-impact data due to lack of anticipation of the occurrence of the environmental disturbance and planning for its management. In the Darwin Harbour catchment fish community data collected in the near future can serve as Before–impact baseline information detection of effects of future disturbances that are different to, or of a greater intensity than, those that have already occurred.

4 Sampling procedures

4.1 Fish behaviour and timing of sampling

During the wet season there is extensive dispersal of fish along river channels and across wetlands. As a result there can be large seasonal changes in the composition and abundance of fish communities at different times of year. This raises the issue of deciding on when is the most appropriate time to sample to obtain the maximum number of species. There is also the question of whether it is desirable, or indeed possible, to obtain other samples from the same site at different times in any one year? Depending on the method used the effect of frequent repeat sampling on the fish should be considered. Apart from visual census techniques, most sampling methods involve handling the fish in some way and this could adversely affect fish and validity of conclusions from repeat samples. Consequently for most management purposes one sampling per year is probably sufficient.

In practice logistic factors may override many of these considerations. For example, many Top-end wetlands are dry for a large part of the year and must be sampled at an appropriate stage of the wet season when (a) water and fish are present and (b) it is possible to obtain access (e.g. by airboat).

Access to riverine sites is very difficult during the wet season due to high flow rates and risk of flooding that make sampling difficult and dangerous. Consequently, the end of the Wet season is when access becomes possible and declining water levels make sampling feasible. Fortunately this is when fish diversity is highest in lowland river habitats making the late-wet-early-dry season the optimal time for sampling riverine locations (Bishop 1990). Later in the Dry season fish diversity and abundance declines. Nevertheless, this can be a relevant time to sample for bioaccumulation of contaminants in fish, but it is not a prime time for assessing biodiversity.

4.2 Sampling effort

Having determined the appropriate sampling methods for different sites it is then necessary to determine the appropriate effort required for each sampling method. A common approach for assessing this is the species accretion curve procedure. In this the cumulative number of species collected is lotted against the increasing amount of sampling effort. An adequate sampling effort is indicated by the effort at which the curve begins to plateau. Another similar approach has been suggested by Streever and Bloom (1993) where the use of multivariate similarity measures is intended (Fig. 3)

The amount of sampling effort takes different forms with different methods. For gill netting the effort is usually measured by the amount of net used and the duration of exposure. Where the nets are set only at optimal times the amount of net is the most appropriate measure. For seine nets the effort can be measured by the number of hauls at a site, while for electrofishing the length or area of stream sampled and the number of passes through it are the appropriate measures.

The optimal sampling effort needs to be established for each monitoring program as there will be considerable variation.

4.3 Sampling costs

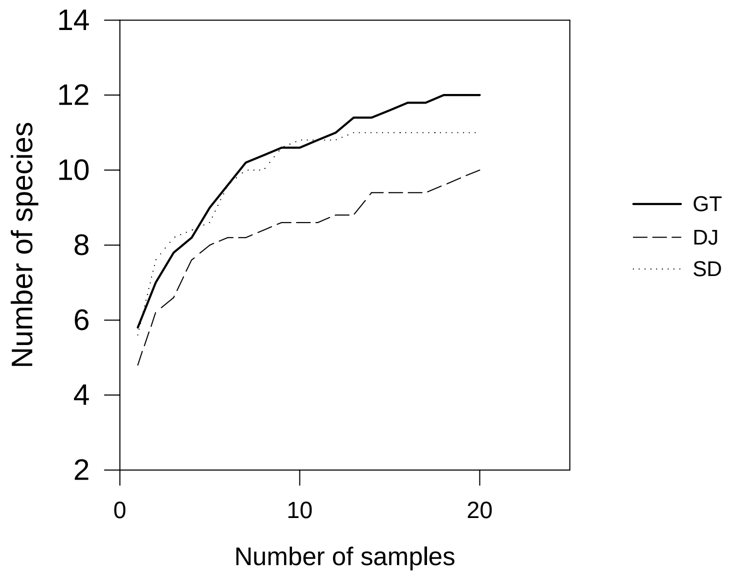
These are important considerations in selection of sampling methods and design of programs. The major costs are personnel and equipment

Personnel costs are determined by the number of people required to operate safely in the field and by the duration of the sampling procedure at each site. The minimum number of personnel may be determined by OH&S regulations of the operating agency. At least two people are required two operate any of the sampling techniques. In Top End streams a third person is recommended to lookout for crocodiles and to assist in the sampling. There may be some initial additional time costs in the training of operators in fish identification and sampling methods. Training in most netting methods is minimal whereas training for electrofishing is a considerable effort involving a minimum number of hours assisting a trained operator (20 hours) and some formal theoretical instruction by short coursework (NSW Fisheries 1997).

The duration of sampling is determined by optimal sampling effort indicated by a pilot study. It should be possible to sample at least one site per day with most netting options. Where this incudes passive methods it may involve sampling at the diurnal peak of fish mobility, often after sunset, making more than one site per day impossible. There is no such restriction with electrofishing in shallow waters and it may be possible to sample two or more sites per day with that method.

Equipment cost varies considerably among sampling methods. The lowest cost options are gill nets and seine nets which should cost less than $2000 to set up a monitoring team. Gill net do require regular maintenance or replacement. Unless already available a small dinghy and electric motor would cost around $3,000. The most expensive equipment is for electrofishing. Back-pack units for shallow streams can cost up to $12,000 and large boat mounted units considerably more, especially if a customised boat is required.

(a) Species summation



(b) Self-similarity

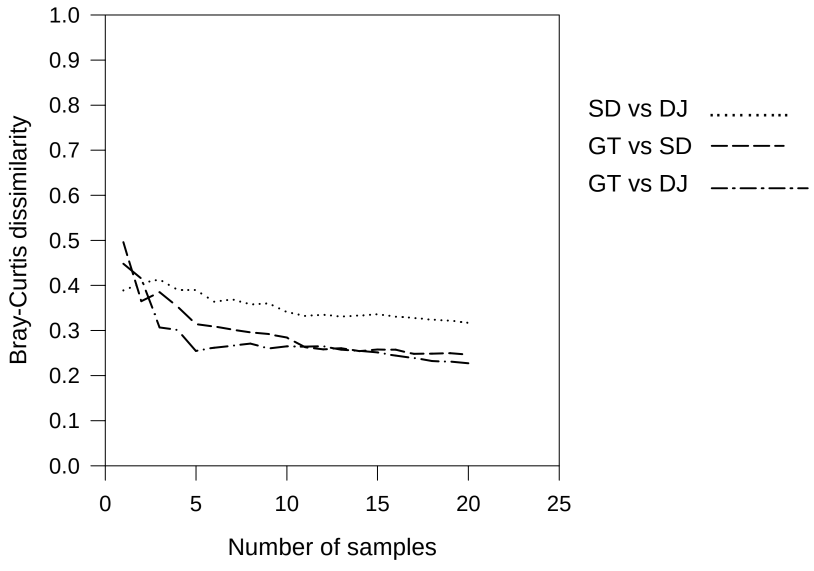


Figure 3 Estimating the sampling effort required to obtain an adequate representation of species composition of fish communities: an example from the use of pop-net traps in Kakadu.

Data are shown for three different billabongs. 20 traps were set in each billabong. Data were analysed by the species summation method and the self-similarity curve method. The species summation method plots the cumulative number of species captured at increasing sample effort. The self-similarity method plots the Bray-Curtis dissimilarity index for the community composition at increasing sample size (no. of samples).

The species summation method indicated at least ten traps were required for the number of species to plateau indicating little likelihood of additional species with further sample effort. The self-similarity method also indicated that 10 trap samples were quite adequate to assure that a reliable indication of the similarity of different fish communities was obtained.

4.4 Selection of sampling methods

Method of fish capture is the most important consideration in designing a fish monitoring program for biodiversity measures, such as the similarity of community structure, species richness, abundance etc. This is because many of the different methods available are highly selective in the array of species and size range of fish that they capture. An example is shown in Table 3 where results of three different methods are compared. As a result of these sampling biases, any change in sampling methodology can have a significant adverse effect on the ability to detect valid temporal changes in biodiversity measures and hence on any inferences derived from them.

Table 3 Numbers of fish detected by different sampling methods in Jim Jim Creek, Kakadu National Park, using three different sampling methods

Gill netting collected mainly larger sized fish and seine netting mostly small fish species. Visual census detected fish of all sizes (Stowar et al 1997)

Scientific Name	Gill-netting	Seine-netting	Visual count*
Neosilurus ater	92	0	25
Nematalosa erebi	76	0	6
Syncomistes butleri	24	0	35
Megalops cyprinoides	29	0	0
Scleropages jardini	27	0	0
Anodontiglanis dahli	25	0	44
Neosiluris hyrtlii	22	0	5
Hephaestus fuliginosus	5	0	38
Arius leptaspis	4	0	0
Lates calcarifer	3	0	11
Toxotes chatareus	4	0	0
Arius midgleyi	1	0	0
Pingalla midgleyi	64	2	45
Leiopotherapon unicolor	45	5	28
Amniataba percoides	122	17	45
Strongylura kreffti	23	1	2
Ambassis macleayi	8	5	0
Glossamia aprion	5	1	1
Melanotaenia splendida inornata	62	376	289
Craterocephalus marianae	0	2313	439
Melanotaenia nigrans	0	321	106
Craterocephalus stercusmuscarum	0	261	267
Ambassis agrammus	0	34	24
Glossogobius giuris	0	18	0
Mogurnda mogurnda	0	3	1
Pseudomugil gertrudae	0	3	7
Denariusa bandata	0	0	1
Total No. of Species	**19**	**14**	**20**

*only made before road opened

Any change in methodology in a monitoring program would require extensive comparative sampling using old and new methods to evaluate effects on the continuity of the temporal dataset. This process is very expensive. However, in some cases this cost could be offset by long term gains where better quality data and lower costs result from a new method.

Where the available sampling methods are highly selective a combination of methods is often used to maximize the species array sampled to potentially include the majority of species present. When this is done it is important to be aware that the abundance of fish captured by different methods is often appropriately expressed in different units. Some abundance measures from active capture methods can be expressed in absolute density terms (numbers per unit area of habitat) but all passive capture and many active methods can only be expressed in terms of catch per unit effort (CPUE) which is appropriate only to the particular gear used. Consequently it is often difficult to combine abundance data from different methods in any other ecologically relevant way, such as total fish density and biomass or relative abundance of species caught by different methods.

A list of common sampling methods for fish in freshwater is provided in Appendix 1. This shows the options available and their advantages and disadvantages for monitoring biodiversity. •OH&S issues (eg crocodile safety), animal experimentation ethics and government regulations may also influence choice of method. From this array the following methods are recommended on the basis of cost of equipment or labour and worker safety. Their suitability for different situations is summarized in table 2.

The least biased method that could be applied to all habitats is *electrofishing*. The conductivity of most streams is above 20 uS/cm (Dostine 2000) and this is just high enough for electrofishing to work effectively. (Cowx & Lamarque1990). Electrofishing has a major advantage in labour cost as it may allow more than one location to be sampled in a day. This advantage is offset by the high cost of the equipment and the possible need for both boat mounted and back-pack units for different situations. Very low conductivity (common in some parts of the NT) and high turbidity can also limit the effectiveness of electrofishers. The cost of hiring the equipment could be explored as an option. Operators of electrofishers need to be trained and become certified by the national Standing Committee for Fisheries and Agriculture (NSW Fisheries 1997).

The least expensive equipment approach is to use a combination of methods to maximize the species array. *Gill nets*, with panels of different mesh size to catch different sized fish, would be used for deep open water habitats in rivers and lagoons. This would sample the larger bodied fish. Small mesh seine nets would be used to sample the array of small bodied fish that are more abundant in shallow and bank edge habitats. Wherever possible the nets would be deployed using a small boat to avoid unnecessary exposure to crocodiles.

Densely vegetated sites in lagoons pose the greatest difficulty. All the methods designed for this habitat (pop-nets, drop-traps) are very labour intensive and not recommended if quantitative density data are not required and alternatives are available. The approach suggested is one used by ***eriss*** on the Magela Floodplain (Douglas et al 2001). This is to clear narrow channels in the vegetation so that small fish can be captured using a small trawl net or dredge pulled through it and, if necessary, larger fish can be sampled using gill nets.

Using this approach it would be unlikely that more than one lagoon could be sampled in a day. Also, there is a marked diurnal variation in fish activity and this affects the array of species and number of fish captured with gill nets at different times of day. There is a marked peak in activity in the hour before and after dark and some species are likely to be missed if these hours are not included in the sampling. Gill netting can be done by two people

5 Recommendations

A fish monitoring program for evaluating success of catchment management strategies can be effectively based on low cost sampling equipment and biodiversity indicators. The use of both gill nets and seine nets is the simplest strategy for establishing baseline data and conducting pilot studies to develop an appropriate design for the DIPE monitoring objectives.

Appropriate sampling methods for different habitats likely to be encountered are indicated in Table 4.

Table 4 Recommended fish sampling methods for different habitats

Habitat	Deep open water	Bank Edge (root mat, debris, undercut)	Shallow open water	Shallow water macrophytes
Main-stem river	+	+	+	+
Small stream	?	+	+	
Lagoons	+		+	+
Sampling technique	Gill net or Electrofishing	Seine (scoop method) or Electrofishing	Seine, electrofishing	Seine, dredge or trawl; electrofishing

It is strongly recommended that baseline studies include sites on suitable control streams where human impacts are likely to be lower than in more closely developed areas. This will of great value in future evaluation of any detected impacts.

If future change to sampling methodology (eg. to electrofishing) is anticipated it should be made early in the development of the program to avoid costly overlap of sampling methods to maintain temporal continuity of monitoring.

Inclusion of measurement of bioaccumulation of contaminants will enhance the public assurance of good management. If staff and laboratory resources for this are inadequate outsourcing of the dissection and chemical analysis could be considered for a small number of specimens and one or two relevant fish species. Species that might be consumed by humans are spangled grunter, barramundi, sooty grunter and fork tailed catfish.

Animal Experimentation Ethics is an issue that must be considered in many institutions for research on vertebrate animals. DIPE should discuss this matter with NT Fisheries to determine the appropriate action in this matter.

It will also be necessary to obtain permission from NT Fisheries Licensing Branch to carry out sampling by other than angling methods. This will involve providing monthly information on fishing activities.

Appendix 1 Sampling methods

1 Passive methods

These are methods that rely on the movement of fish to capture them.

Gill nets

Lengths of netting stretched out vertically in water by weights and floats. Swimming fish collide with net and get caught while trying to pass through. Different mesh sizes catch fish of different sizes.

Advantages

Easy to use and commercially available. Very effective on many larger bodied fish. Can operate in deep open water as well as shallow open waters.

Disadvantages

Very small mesh sizes are not very effective on smaller fish sizes biasing method towards larger fish species. Meshing of fish can cause damage to fish. Some species such as banded grunter and bony bream can be difficult to remove without significant damage to the fish. Great care is needed if repetitive sampling is to be carried out so that the sampling does not affect numbers available at subsequent sample times. Mortality can be minimized by operators staying near nets and removing fish soon after they are captured. Holding released fish in fine mesh pens can prevent them re-entering nets and allows evaluation of short-term mortality. Provides only CPUE measures of abundance.

Trammel nets are similar to gill nets but have rows of pockets along the net for fish to get wrapped in. May have advantages in shallow tidal situations

Fish traps: (Bait fish/minnow traps, Fyke nets, Trap nets)

Mesh enclosures with funnel shaped entrances to allow fish to enter and inhibit their exit. There are many different designs. Fyke nets and trap nets have panels of “lead” net to direct the fish into the trap.

Advantages

Can operate in most habitats except very dense vegetation. Size and species bias differs greatly between types of trap. Less bias with finer mesh size on fyke and trap-nets (Hayes 1989) and these have less size bias than gill nets. Mortality rate is very low making it easy to identify and return fish.

They can be left in place for prolonged period if required. This enables the sample to encompass are range of diurnal patterns of fish movement and can allow more than one site to be sampled at one time. Access to the surface for air breathing fauna should be provided. This is easier to do in shallower water.

Disadvantages

Gear for larger traps is bulky and cumbersome and labour intensive to set up. It is generally not commercially available. Provides only CPUE measures of abundance. Biased towards most active fish and some species less trappable than others. Minnow traps are readily available commercially but they are highly selective and variable in effectiveness even when baited.

2 Active methods

These are methods that somehow seek out the fish and employ a device to capture them. They are not reliant on the natural movement of fish to effect the capture.

Seine (Drag) nets

Length of netting weighted at the bottom and supported by floats at the top which is set to enclose an area and then dragged to the shore. On larger nets there is often a deep pocket (purse) built into the centre for fish to collect in and minimize their escape.

Advantages

Short sampling time. Low fish mortality. Some nets are commercially available and any design is easy to obtain from netmakers. Low cost.

Disadvantages

Not very effective in even moderately vegetated sites. Catch is dependent on mesh size but is also biased towards smaller/slower fish that are less able to avoid the net. Provides only CPUE measures of abundance because of difficulty in standardizing the area fished. Typically involves operators entering water and exposure to crocodile risk. Shorelines are often not suitable for beaching the seine

Trawls

Cones of netting that are dragged through the water behind a boat, usually at or close to the bottom with devices to keep the entrance funnel extended and the trawl net at the required depth.

Advantages

Easy to use. Can sample large areas of habitat. Low mortality with short trawls.

Disadvantages

Can operate only in open water with a relatively clear bottom Limited use in freshwater streams and wetlands because of bottom structure. Ineffective in vegetation. Small beam trawls can be effective in tidal reaches with clear bottoms. Not commercially available. Bias in fish size related to mesh size which affects minimum size retained and speed of tow and hence ability of fish to avoid trawl.

Provides only CPUE measures of abundance.

Electrofishing

Electrofishing is now one the most widely used methods for sampling freshwater fish for both biodiversity and population measurements. It involves the use of pulsed electric current to temporarily immobilize fish enabling their capture with a hand net as they come to the surface, or to cause fish to swim along a directional field towards one electrode (galvanotaxis) where they can be captured by a hand net.

Advantages

Can provide estimates of density. Can capture a wide range of fish sizes but catch biased towards larger fish. Relatively short sampling time. Easy to target specific habitats and times. Commercially available

Disadvantages

The impact on fish is unclear. Variation in pulse structure is required to sample different size fish. The higher frequency required for smaller fish can kill larger fish. Multiple passes through fished areas using different pulse settings can reduce this risk (Pusey et al 1998).

The equipment can be very expensive ($30,000 -$50,000 for a large boat mounted unit) but small back-pack units are less expensive and can be hired. Difficult to use in dense emergent vegetation.

Effectiveness is reduced at very low temperatures and in high and low conductivity waters. Also less effective in turbid waters where stunned fish under the surface cannot be seen.

Boat based units powered by generators are useful only in larger streams and open water lagoons and billabongs. In smaller streams back-pack battery operated units are generally used but this involves entering the water and exposing operators to crocodile risk. Operators need to be well trained in use and safety procedures. High risk of electric shock. The need to wear insulating gloves and waders has the potential to cause rapid weight loss in operators in the tropics.

Fish poisoning

The use of fish poisons is widely used in fish surveys by taxonomic researchers in situations where rapid dilution by tidal movement can occur eg in inter-tidal rock pools. Whilst fish poisons are used by indigenous peoples in northern Australia for gathering food in freshwater pools they are not widely used by scientists in fish surveys because of the difficulty of either diluting the toxin or neutralizing it. Rotenone, the active ingredient of derris root powder, is the most common commercially available product used for this purpose. This acts on the gill membranes blocking the uptake of oxygen by affected fish. There are a number of native Australian trees whose bark produces extracts that can induce fish kills (Bishop et al 1982).

Advantages

Can sample all species, especially more cryptic species and mobile species that are difficult to capture when alive. No species or size bias.

Disadvantages

Kills every fish in pool or reach of stream or lagoon. Risk of killing fish in non-target areas. Cannot be used where repeat sampling is required.

Visual census

This involves counting fish by observation without capturing them. Various counting techniques have been used such as transects, fixed plots, random point observation in a manner similar to visual census of large terrestrial fauna. Widely used in marine situations such as coral reefs where visibility underwater is very good. Visibility in freshwater is generally not good enough and large predators can be a deterrent in the tropics. Clear flowing water in Top End streams at the end of the wet season provides some opportunity for this technique. Used effectively in some situations in Kakadu.

Advantages

Does not harm fish and is ideal for repeated sampling which is desirable in some politically sensitive situations. No size or species bias. Can provide density measurements.

Disadvantages

Visibility and water depth. Discrimination of physically similar species often difficult or impossible.

Pop-net traps

Bottomless enclosures of netting that can be placed in aquatic vegetation to be later triggered to rise and trap fish within the enclosure. Vegetation is subsequently removed and then the fish are removed by dip nets or small seines.

Advantages

One of few methods that work in dense vegetation. No species bias. Little bias in fish size. However, when very small enclosures are used larger fish are difficult to trap.

Provides measurements of fish density.

Disadvantages

Depth limitation to water <1 m deep. Vegetation damage. Larger nets can be heavy and labour intensive to set and clear. Not commercially available. Cost is dependant on chosen size and design. Wading in water is required and provides risk of exposure to crocodiles (may require expensive safety nets).

Drop net traps and throw traps

These are devices that enclose areas of aquatic vegetation in shallow waters by dropping from above. Drop nets are netting enclosures dropped from a supporting frame standing above the water. Throw traps are heavy metal enclosures that are thrown from a boat to cut through vegetation to surround fish. Fish are removed from traps using dip nets or small seines, as with pop-nets.

Advantages

No species bias. Little bias in fish size. However, when very small enclosures are used (throw traps) larger fish are difficult to trap.

Provides measurements of fish density.

Disadvantages

Similar to pop –nets. Depth limitation to water <1 m deep and vegetation damage. Not commercially available. Cost is dependant on chosen size and design. Wading in water is required and provides risk of exposure to crocodiles (may require expensive safety nets). Do net penetrate very dense vegetation very well.

Cast nets

Weighted circular pieces of netting that are thrown by hand to extend over water surface and drop to surround fish and trap them inside the net or entangle them in the mesh. Widely used around the world in artisanal fisheries and in recreational bait fish capture.

Advantages

Commercially available and relatively inexpensive. Once operators are trained they are easy to use from boats or shore where substrates are suitable.

Disadvantages

Difficult to quantify area sampled. Not effective in deep water, dense vegetation or areas with rough bottoms or locations with snags. Very low capture efficiency.

Appendix 2 Sampling Equipment Suppliers

Nets

Terry Gorman and associates

PO Box 340, Newport Beach
NSW 2106 Australia

ABN 95715 235 501

Tel: 02 9979 7269
Fax: 02 9997 4203

e-mail:tgorm@optusnet.com.au

(good source of fine multi-panel gill nets imported from Denmark)

Australian Netmakers

9 Rees Street
O'Connor WA 6163

P.O Box 291 Hamilton Hill 6963

Tel: (08) 9331 1955
Fax: (08) 9337 6582

attica@iinet.net.au

A.B.N 82 008 800 762

(very reliable supplier of customised nets)

Darwin Shipstores

Fishermans Wharf
Frances Bay Drive, Darwin

8981 7322

(Good source of net materials and can arrange net making)

Electrofishing

Marine Navaid Systems

Sydney
(02) 9313 8766

(Australian suppliers of Smith-Root electrofishers)

Andrew Bruce

NSW Fisheries
Aquaculture and Sustainable Fisheries Division
Pt Stephens Fisheries Centre
Private Bag 1
Nelson Bay NSW Australia 2315

ph 02 4916 3814 (Int: + 61 2 4916 3814)
fax 02 4982 2265 (Int: + 61 2 4982 2265)

mob 0428 417 627

email Andrew.Bruce@fisheries.nsw.gov.au

(Contact for advice on different brands of electrofishers and suppliers. Also source of information on training and Code of Practice)

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