CRC REEF RESEARCH TECHNICAL REPORT

A REVIEW OF ENVIRONMENTAL IMPACT MONITORING OF PONTOON INSTALLATIONS IN THE GREAT BARRIER REEF MARINE PARK

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EXECUTIVE SUMMARY

Tourism is an economically and socially valuable activity in the Great Barrier Reef Marine Park. Pontoons moored offshore provide a stable and convenient platform from which tourists can experience remote areas of the Great Barrier Reef (GBR) with ease and comfort. Visitors are ferried to and from pontoons by large, high-speed vessels daily, but cannot stay overnight on pontoons. There have been 19 pontoons used on the GBR, though fewer than this are currently in operation.

The objectives of this report were to review pontoon monitoring programmes, synthesise and re-analyse data from them and to make recommendations about the design and implementation of future monitoring programmes at pontoons. The report is based solely on documented evidence and does not consider influences such as 'corporate culture', experience, political pressures, and personal judgement of those administering pontoon monitoring.

The first systematic monitoring of the ecological impacts of pontoon installation and associated activities was at Agincourt Reefs in 1986-87. That monitoring programme was initiated by tour guides working with the pontoon operator. Since 1989, the Great Barrier Reef Marine Park Authority (GBRMPA, the Authority) has required all pontoon operators to fund an independent monitoring programme to assess the environmental impacts of pontoon operations. Although the developer funds monitoring, independent consultants under contract to the GBRMPA do the monitoring. This mechanism maintains important financial and operational distance between developer and monitoring consultants and it is expected that this separation of consultants and proponents will favour impartial assessments of impacts. This should continue to be the basis of monitoring project management.

Pontoon monitoring programmes to date have been cast generally in the sound framework of Before-After, Control-Impact (BACI) designs. The GBRMPA was among the earliest agencies to attempt to implement BACI monitoring programmes systematically. There has been considerable variation in the success of implementing these designs, however. The result is that the 11 monitoring programmes we reviewed differed in fundamental ways. This heterogeneity has resulted in a lack of rigour in the synthesis of results and the learning value of the collective monitoring programmes. Individually, many pontoon monitoring programmes were found to be deficient in design, implementation and analysis. The main deficiencies we found included: poorly specified objectives, insufficient baseline monitoring, too few control sites, insufficient post-installation monitoring, frequent and confounding changes in methodology, errors in statistical analyses, and lengthy delays in reporting. In all cases, the likelihood that monitoring would have detected real impacts was low unless those impacts were extreme. Responsibility for these shortcomings must be shared between the Authority, Proponents, and Consultants. Responsibility for correcting procedures to avoid such mistakes in future should fall to the Authority.

Despite these many problems, it was clear that early pontoons had some major impacts on reef biota, particularly when moored over reef substrata with early mooring systems. Changes to mooring technology and mooring pontoons over sediment substrata have reduced or eliminated these impacts. There is weak evidence from monitoring to date that activities such as snorkelling and resort diving near pontoons have small impacts on corals, but the long-term consequences of those impacts are unknown. All pontoons result in the aggregation of several species of fish, but there is no conclusive evidence that these aggregations cause impacts on other biota (or that they don't).

We recommend that pontoon monitoring should continue, but should be streamlined and more specifically targeted at known activities and their most likely impacts. Monitoring must be better designed, and good designs better implemented, and should be standardised across pontoon installations if it is to fulfil expectations, provide best value for money, and maximise benefit to the future management of pontoons and associated activities. Once properly designed, monitoring should be standardised for a defined period (3-5 years) and then reviewed and refined in the light of then current knowledge and technology.

I INTRODUCTION

Increasing concern about the ethical and economic trade-offs between exploitation and conservation of natural biological resources in recent years has placed greater pressure on environmental managers. The Great Barrier Reef (GBR) is a particularly topical case, both within Australia and world-wide. The gazetting of the Great Barrier Reef Marine Park (GBRMP) as a multiple use marine park explicitly demanded the conservation of the biological characteristics of the Great Barrier Reef in the context of ongoing recreational use and commercial development (GBR Marine Park Act, 1975). As manager of the GBRMP, therefore, the Great Barrier Reef Marine Park Authority (GBRMPA, the Authority) is faced with balancing the interests of an array of commercial activities (*e.g.* tourist industries, fin, crustacean and sessile invertebrate fisheries, commercial shipping), recreational users, Aboriginal users, and research groups, whilst endeavouring to ensure that the bio-physical system is conserved. Management in this context effectively entails the regulation of human use, *e.g.*, by zoning areas for different allowable uses, rather than intervention in natural bio-physical processes *per se* (Hendee *et al.* 1990, Kelleher & Kenchington 1991, Kenchington 1990). The favoured regulatory strategy to date has been to zone the GBR for differential access and use, and allow specified commercial or research uses under a system of permits.

The success of such regulatory management should be assessed with reference to two variables: i) the status of the ecosystem that is to be conserved, including in response to human use; and ii) the degree to which human use is facilitated to the satisfaction of users. Monitoring the status and dynamics of the natural system, and of human use of the system, therefore, provides the feedback necessary to assess the success or failure of management strategies. In particular, monitoring the impacts of permitted activities on the GBR is crucial to the review of those activities and assessment of whether, and if so how, they should be allowed to continue. The quality and quantity of information derived from such monitoring is critical to the evolution of prudent and justifiable management (Hendee *et al.* 1990). The importance of deriving this information soundly has been emphasised by the considerable material published recently on methods for marine impact monitoring (Fairweather 1991a,b, Green 1979, 1989, 1993, Hayes 1987, Millard 1987, Keough & Mapstone 1995, Mapstone 1995, 1996, Schmitt & Osenberg 1996, Stewart-Oaten 1996a,b, Stewart-Oaten et al 1986, Underwood 1991, 1992, 1993, 1994, and others).

Tourism has become perhaps the most important economic activity in the GBRMP over the past decade. Moored pontoons have become a common base from which to 'show off' the GBR to tourists, providing a stable platform off-shore to which visitors can be shipped and from which they can experience the GBR first-hand, either by snorkelling, SCUBA diving, fishing (in some cases), or through viewing opportunities at underwater windows on the pontoon or smaller, mobile semi-submersible vessels. There have been at least 19 pontoons installed on the GBR, though some of these have since been removed. Collectively, the pontoons now moored on the GBR, mainly in the Cairns Section of the Marine Park, cater for several thousand tourists daily, who are ferried to and from the pontoons from major coastal centres. No pontoons are permitted for over-night visitation by tourists.

As with other forms of tourism, tourism based on pontoon installations generally relies on the aesthetic qualities of the reef near pontoons for its attraction and, at least partly, for the satisfaction of the visitors. Perceived degradation of particular sites as a result of pontoon installation or pontoon-based activities has the potential, therefore, to impact on the economics of tourism industries. Real degradation of pontoon sites represents a potential threat to the ecological conservation of the Great Barrier Reef, at least locally. The clear identification of what ecological impacts can be expected from pontoon installations will allow better planning to ameliorate or counter such impacts and their consequences. Accordingly, many of the pontoons moored on the GBR in recent years have had associated with them environmental monitoring programmes intended to assess the ecological impacts of pontoons and pontoon-based activities.

The first monitoring of a pontoon installation on the GBR seems to have been initiated by a tour-guide company (Reef Biosearch) working in conjunction with a company operating one of the earlier pontoons (at Agincourt Reefs, off Port Douglas). That programme was mainly industry funded (voluntarily), although requests to the GBRMPA for additional funding were made in 1987. Since then, monitoring the (potential) impacts of pontoons has become obligatory, and issue of a permit to operate a tourist pontoon has generally been conditional on the funding by the proponent of a suitable monitoring programme. The GBRMPA has set in place procedures that ensure that the consultants who do the monitoring are managed by the Authority rather than by the proponents, and it is expected that this separation of consultants and proponents will favour impartial assessments of impacts. All the pontoon monitoring programmes to date (apart from the first) have been managed on this concept. These monitoring studies had not been collated, however, and their strengths and weaknesses had not been assessed collectively.

This project involved the review of reports arising from these programmes, synthesis and some re-analysis of the data from them, and evaluation of those variables that should continue to be monitored, dropped from monitoring programmes, or introduced to monitoring programmes. We made recommendations about the design and implementation of pontoon monitoring for future installations such that existing knowledge is complemented, rather than duplicated, and past weaknesses might be avoided in future.

The objectives of this report, then, were to:

? Review the sampling designs, implementations, data, and conclusions from monitoring programmes intended to assess the impacts of pontoons moored on the GBR to 1995;

? Synthesise data from those monitoring programmes;

? Identify consistent ecological impacts of pontoons from the available data;

? Provide recommendations about sampling designs, variables to measure, and general aspects of implementation for future pontoon monitoring programmes.

II REVIEW METHODS

2.1 Sources of Data

This review covered monitoring at eleven pontoons on the Great Barrier Reef (GBR) (Table 2.1). Data for the review were collated from two types of source. First, reports prepared by consultants were searched for information about designs, methods and results of monitoring. A list of all reports surveyed is given in Table 2.2. Second, raw data from the monitoring studies provided by the Great Barrier Reef Marine Park Authority (GBRMPA) were used to re-analyse results of monitoring where appropriate.

Table 2.1 Pontoon operations on the GBR from which monitoring programmes were reviewed.

Reef / Pontoon	Operator	Established	Size (l x w, m)	Visitors/day[8]
Agincourt 2d	Quicksilver	August[1] 1984	30 x 12.5	300
Agincourt 3a	Quicksilver	June 1987[2]	30 x 12.5	300
Agincourt 4	Quicksilver	June 1990	30 x 12.5	300
Arlington	Sunlover	June 1992	46 x 12	
Hardy	Fantasea	December 1992	53 x 15	600
Kelso	Pure Pleasure	December 1990	30 x 10	-
Low Isles	Quicksilver	June 1986	24 x 9	156
Moore	Great Adventures	1989[3]	25 x 10[6]	600
Moore	Sunlover	October 1991	46 x 12	300
Norman	Great Adventures	May 1987[4]	45 x 15[7]	300[9]
Wistari	P&O Resorts	February 1989[5]	45 x 16	-

[1] Replaced June 1986; [2] Removed June 1990; [3] Replaced December 1992; [4] Replaced June 1992;
[5] Decommissioned March 1992; [6] Replacement pontoon 46 x 12m; [7] Replacement pontoon 49 x 16m;
[8] Visitors/day are maxima permitted for each pontoon [9] Capacity of replacement pontoon was 700 visitors/day

Table 2.2 Reports prepared by consultants on monitoring at pontoons 1988-1995. The date against each report is the date of the Final Report. Full details are in the reference list.

Pontoon	Author(s)	Year
Agincourt 2d	Richards Marine Environmental Monitoring	1992 1995
Agincourt 3a	Richards Gibson *et al.*	1992 1994
Agincourt 4	Gibson *et al.*	1993
Arlington	Sinclair Knight Merz Ayling & Ayling	1994 1995a
Hardy	Ayling & Ayling	1994a
Kelso	Sinclair Knight Merz	1993a
Low Isles	Marine Environmental Monitoring	1994
Moore (GA)	Ayling & Ayling	1994b
Moore (SL)	Sinclair Knight Merz Sinclair Knight Merz Sinclair Knight Merz Ayling & Ayling	1992 1993b 1993c 1995b
Norman	Ayling & Ayling Ayling & Ayling	1989 1994c
Wistari	Fisheries Research Consultants Fisheries Research Consultants	1991 1992

Throughout the report, we refer to each pontoon by the reef on which it was moored. If more than one pontoon was moored on a given reef, the operator's initials are suffixed to the reef name. For example, the pontoon at Agincourt reef 2d is simply referred to as 'Agincourt 2d', whilst the pontoons run by Sunlover and Great Adventures at Moore Reef are referred to as 'Moore-SL' and 'Moore-GA' respectively.

To review the administration and management of pontoon monitoring by GBRMPA, we searched through files relating to each pontoon for information about timing of projects, reviews of proposals and reports, and any additional information of relevance to administration of each monitoring programme. The GBRMPA also provided the document 'Draft Guidelines for Monitoring Programmes' which we used as our guide to administrative and funding procedures. We also requested from GBRMPA staff any additional written material they considered relevant to the review. Our emphasis was on what had been done in monitoring programmes and how they had been managed, as bases for the design, implementation, and management of future programmes. We did not attempt to review permitting procedures for pontoons, pre-permitting impact assessment (or prediction) procedures, or attitudes of proponents, Authority staff, or consultants to pontoon monitoring. This approach meant that we relied entirely on documented information. Although 'corporate culture', experience, political pressures, and judgement inevitably played a role in decisions about pontoon monitoring, a thorough audit of such factors was beyond the scope of this review. In general, however, such opaque influences on decisions might be seen as undesirable because the absence of their documentation is likely to impede understanding of past decisions and their propagation into future decisions.

2.2 Review of Design and Analysis

Monitoring to detect [potential] impacts of pontoons and associated activities on the GBR has concentrated on three main areas: effects on benthic assemblages, effects on fish assemblages, and effects on water quality. To assess the quality of the data collected about impacts we first evaluated the designs of the monitoring programmes, the variables measured, and the appropriateness of methods used to collect and analyse data. The programmes were assessed with particular reference to the recent literature on monitoring programme designs appropriate or necessary for assessing the presence and magnitude of human environmental impacts.

We outline briefly below the main elements of sampling design we sought in reviewing existing monitoring designs. Our selection reflects discussions in recent literature relevant to monitoring environmental impacts, especially where multiple control sites are possible (Andrew & Mapstone 1987, Bernstein & Zalinski 1983, Green 1989, 1993, Keough & Mapstone 1995, Millard & Lettenmaier 1986, Underwood 1981, 1991, 1992, 1993, 1994). The key features we sought were:

1. ***Clear statement of the aims.*** The overall reason for monitoring should have been clearly stated. For example, was monitoring mainly exploratory (‘we need to see what happens when a pontoon is installed’) or to provide information for specific management actions (‘if impacts exceed some amount, the pontoon will have to be (re)moved or changed’)? For the latter, objectives should have been stated quantitatively, with reference to the amount of change in specific variables considered to be important (as an impact) and to which monitoring should be designed (Oliver 1995).
2. ***Identification of the key variables to be measured***, and why.
3. ***Adequate baseline data.*** Baseline data provide information about natural spatial and temporal variation before an impact occurs. Multiple sampling times before pontoons are

installed provide a background of temporal variation (at both pontoon and control sites) against which to measure impacts. Without multiple sampling times before pontoon installation, the monitoring programme is confounded, and it is not logically possible to infer that an impact occurred because there is no way of knowing that the change measured is outside the range of natural temporal variation that would have occurred in the absence of a pontoon (Stewart-Oaten *et al.* 1986).

4. ***Multiple control sites.*** Coral reefs and their associated fish assemblages are naturally highly spatially variable (Done 1982, Williams 1991, Nelson 1992, 1994, Sale 1980). For example, any two sites are likely to have naturally different benthic community structures and fish assemblages. For this reason, any site with a pontoon is likely to differ from any single control site. With only a single control site, there is no measure of the expected natural variation among sites, or their temporal behaviour, and no basis on which to decide whether a change at the pontoon site was likely to have been a real impact caused by a pontoon or just natural variability among sites. The result could be the incorrect inference of an impact. The more control sites sampled, the better the estimate of [natural] variation among them and the sounder the basis for assessing a) the similarity or difference between control sites and the pontoon site prior to installation, and b) the meaning of shifts in measured variables at the pontoon site following installation of the pontoon. Further, including more control sites improves the statistical power to detect differences (either at one time or through time) between the single pontoon site and the un-impacted environment. Obviously, the larger the number of controls, the more powerful the test and the more likely it is that an impact will be detected should it occur.
5. ***Methods, and scale of spatial and temporal sampling.*** We looked for evidence about whether the sampling methods were appropriate to the variables measured and the objectives of the programme. We also considered the ways in which sampling units were allocated within sites and/or times, and the distribution of control sites with respect to the impact site. Several authors have emphasised the need for repeated sampling of control and impact sites both before and after the commencement of a putative source of impact (Green 1989, 1993, Keough & Mapstone 1995, Stewart Oaten 1995a, Stewart Oaten *et al.* 1986, Underwood 1991). We assessed the degree to which the past pontoon monitoring designs had any temporal component of sampling and the appropriateness of it to the stated objectives (where possible). Our chief interest was whether the methods, their allocation in space, and the number of times sites were sampled resulted in sensitive tests for the presence of impacts.

In addition to the above key design features, we considered the appropriateness of the statistical analyses used in the monitoring programmes, given discussions in the above literature. Because there has been considerable development of impact assessment methods in the last 10 years, there was the risk that we were over-critical on the basis of hind-sight. We endeavoured to temper this risk by reference to contemporary reviews of each monitoring programme, and focussed mainly on issues that were known at the time the programme was designed and implemented.

Although most of the relevant literature post-dates the earlier pontoon monitoring studies, it is noteworthy that most of the key features we sought were present in the first reported study (1987), and flagged by various reviewers thereafter. We infer, therefore, that our expectations were not out of step with reasonable contemporary knowledge for most or all monitoring programmes.

2.3 Review of Results

2.3.1 Benthic Assemblages

The main aim of this section was to summarise what has been shown about the impacts of pontoons on benthic assemblages. We did this in three ways. First, we summarised statistical results and inferences from the original reports. Second, we investigated the magnitudes and directions of changes at pontoon and control sites to see whether there were any indications of consistent impacts undetected by statistical analyses. Third, we combined the data from the monitoring programmes (where possible) to test whether pontoon sites on average had behaved differently from control sites over the period of the pontoons' installations and operations.

Some data were re-analysed using statistical models more appropriate to BACI designs than those used in original work. At four pontoons (Agincourt 3a, Agincourt 4, Hardy and Moore GA), monitoring was set up at one 'impact' site and two or more 'control' sites. An assumption implicit in this approach was that the scale over which an impact of a pontoon might occur was covered by the (single) pontoon site, and 'natural' phenomena occurring at the same scale would be measured by each control site. Hence, the effective unit of replication of pontoon or control 'treatments' was one site (Keough & Mapstone 1995). An impact would be detected by comparing changes at the impact site with the average of changes (and variation in them) at control sites (Underwood 1991). In this case, variation among control sites in their behaviour through time was not interesting *per se*, except in that it provided a yardstick against which to interpret changes at the impact site (but see Underwood 1992, 1993, 1994 for discussions of circumstances where such among-site variation might be important).

In reanalysing these data, we used an unbalanced design with two main effects: Impact (Pontoon *vs* Control) and Time (Keough & Mapstone 1995). Time here was a repeated measure (Green 1993, Keough & Mapstone 1995). The source of variation of interest was the Impact*Time interaction, which would indicate whether the pontoon site behaved differently through time than the average of the control sites. Sites were nested within the Control and Impact treatments (Keough & Mapstone 1995, Underwood 1992, 1993). The re-analyses were done with univariate repeated measures analysis of variance on untransformed data. To guard against errors caused by violations of the assumption of sphericity, we adjusted the degrees of freedom for all tests of Time effects by the Huynh-Feldt epsilon (Huynh & Feldt 1970, Winer *et al.* 1991).

To synthesise data available and provide an indication of whether there were any consistent impacts of pontoons on benthic communities, we compared the magnitude and direction of changes at control and impact sites across all pontoons. We did these tests for total hard coral cover, total soft coral cover, and coverage by those common families of coral that had most often been sampled (Acroporids, Pocilloporids, Faviids, Poritids). To standardise the data among pontoons monitored at and over different periods, we calculated the average annual rate of change in coverage at each pontoon or control site. We did so simply by dividing the absolute change in cover over the entire period of each study (the percent coverage at the end of the study minus the percent coverage before the pontoon was installed) by the time between the two measurements (in years). This approach was based on the assumption that changes in coverage were approximately linear with time. Although contrary theoretical arguments exist, none of the data provided were sufficient for us to test that assumption. Statistical comparison of the annual changes in cover of corals at control and impact sites was done by t-tests for each variable. T-tests were adjusted for unequal replication and variances where appropriate. Our emphasis was on the synthesis of results across studies rather than the re-analysis of results of each study. Because of the great variation in methods, design, and data among studies, our synthetic analyses were necessarily simple, and did not allow us to examine some of the more subtle aspects of sampling at particular pontoons.

2.3.2 Fish Communities

The aims of this section were to document the size and composition of fish aggregations at eleven pontoons, summarise spatial and temporal patterns in fish communities at pontoons and nearby control locations, and to investigate the factors which appeared to influence the nature of fish aggregations. We searched through reports and raw data for total counts of fish aggregations underneath pontoons for an estimate of the maximum size and composition of the aggregations. Spatial and temporal patterns in fish assemblages were investigated by summarising monitoring of transects or rapid visual surveys at pontoon and control locations. The abundances of fish under pontoons estimated by these two methods (total counts *vs* transects or rapid visual counts) differed widely because the fish aggregations were by nature patchy and mobile, and so may not have been included in counts along transects or in rapid visual counts. We did not re-analyse the fish data, even though existing analyses were inappropriate in many cases. We concentrated on the monitoring of benthic assemblages at the expense of treating fish data in detail because Sweatman (1996) has recently completed a thorough investigation of the effects of pontoon installations on fish behaviour and the formation of aggregations.

2.3.3 Water Quality

Data on water quality were collected at four pontoons (Agincourt 2d, Agincourt 3a, Agincourt 4 and Moore-SL). Data were generally few, and we simply summarised them here.

2.4 Management and Administrative Procedures

To assess management and administrative procedures, we searched through files containing correspondence pertaining to each pontoon, including project proposals and reviews of proposals and reports. From these files and from the GBRMPA draft monitoring guidelines, we summarised administrative procedures and compared the theoretical steps with the steps taken in practise. For each pontoon, we constructed a time line indicating when monitoring proposals were submitted and reviewed, when field work occurred, when the pontoon was installed and when reports were received, reviewed and resubmitted. The reviewers' comments were used collectively to assess how efficient the transfer of information and reviewers' comments was among monitoring programmes. Time lines were also useful to comment on transfer of information because they provided a perspective on the extent to which it would have been possible to learn from one monitoring programme before implementing another.

III DESIGN, DATA COLLECTION, AND ANALYSIS

3.1 Benthos Monitoring Programmes

Benthic monitoring programmes have addressed three types of impacts:

i. The effects of the pontoon 'footprint' (the area immediately under the pontoon);

ii. The effects of snorkelling activities; and

iii. The effects of diving activities.

Not all impacts have been studied at all pontoons. Table 3.1 shows what monitoring was done at each pontoon.

Table 3.1 Types of impact monitored at each pontoon. ✍= impact monitored; ✍ = impact not monitored

Pontoon	Footprint	Snorkelling	Diving
Agincourt 2d	✍	✍	✍
Agincourt 3a	✍	✍	✍
Agincourt 4	✍	✍	✍
Arlington	✍	✍	✍
Hardy	✍	✍	✍
Kelso	✍	✍	✍
Low Isles	✍	✍	✍
Moore-GA	✍	✍	✍
Moore-SL	✍	✍	✍
Norman (1987-1988)	✍	✍	✍
Norman (1992-1993)	✍	✍	✍
Wistari	✍	✍	✍

3.1.1 Overview

All benthic monitoring was based on estimates of percent coverage by hard corals and soft corals. The taxonomic resolution varied among monitoring programmes, ranging from species-level identifications to gross identification only as 'hard' or 'soft' coral. For studies at Agincourt, Hardy, Moore-GA and Norman reefs, corals were identified to species or genus and life form, but were lumped into families for analysis. The taxonomic resolution used in monitoring different types of pontoon impacts (footprint, snorkel and dive impacts) also differed among pontoons, and even within some monitoring programmes (Table 3.2). The only common variables measured across all pontoons were total cover of hard corals and total cover of soft corals. In addition to estimates of percent coverage, size structure of populations of some families, levels of damage, and heights of corals were measured at some pontoons (Table 3.2). Height of corals (or width of plating corals) and damage were generally recorded only in surveys by Ayling & Ayling, whilst observations on tagged individuals were mostly a feature of some studies by Sinclair Knight (P/L). Whilst there was generally no rationale for measuring percent coverage articulated in the reports (or proposals), it is a sufficiently widely used method for describing reef benthic assemblages that such rationale was seen as unnecessary. What was absent, however, was discussion of whether changes in percent coverage were likely to be the most sensitive or relevant indicators of impacts for all activities associated with pontoons. The introduction of other measurement variables (such as breakage) was generally justified only briefly, and without reference to empirical evidence of their sensitivity as measures of impact.

Table 3.2 Benthic variables analysed for monitoring the effects of pontoon footprints (F), snorkel (S), and dive (D) activities.

% Coverage of:		**Pontoon**										
Category	**Sub-group**	**Agin2d**	**Agin3a**	**Agin4**	**Arlingt[n]**	**Hardy**	**Kelso**	**Low**	**Mor-GA**	**Mor-SL**	**Norm[n]**	**Wistari**
Acroporids	**Total**	-	-	-	-	S,D	F[1]	-	S,D	F,S	F,S,D	-
	Branching	F,S	F	F	-	-	-	-	-	-	-	-
	Other	F,S	F	F	-	-	-	-	-	-	-	-
	Montipora	F,S	F	F	-	-	-	-	-	-	-	-
	Isoporans	S	-	-	-	-	-	-	-	-	-	-
Pocilloporids		F,S	F	F	-	S,D	-	-	S,D	F,S	F	-
Faviids		F,S	F	F	-	S,D	F[1]	-	S,D	F,S	F,S,D	-
Poritids	**Total**	F	F	F	-	S,D	F[1]	-	S,D	-	S,D	-
	Massive	F	F	F	-	-	-	-	-	F,S	-	-
	Branching	F,S	F	F	-	-	-	-	-	-	-	-
Agariciids		F,S	F	F	-	-	-	-	-	-	-	-
Mussiids		F,S	F	F	-	-	-	-	-	-	-	-
Siderastreids		F,S	F	F	-	-	-	-	-	-	-	-
Millepora		F,S	F	F	-	-	-	-	S,D	-	F,S	-
Other Hard Coral		-	-	-	-	-	F[1]	-	-	F	-	-
Total Hard Coral		F	F	F	S,D	S,D	S,D	-	S,D	F,S	F,S,D	F
Dead Coral		-	-	-	-	-	-	-	-	-	F,S	-

Table 3.2 (Continued)

% Coverage of:		Pontoon										
Category	**Sub-group**	**Agin2d**	**Agin3a**	**Agin4**	**Arlingt^n**	**Hardy**	**Kelso**	**Low**	**Mor-GA**	**Mor-SL**	**Norm^n**	**Wistari**
Soft Coral	**Total**	F	F	F	-	S,D	F,S,D	-	S,D	F,S	F,S,D	F
	Sinularia	-	-	-	S,D	-	-	-	-	-	-	-
	Sarcophyton	-	-	-	S,D	-	-	-	-	-	-	-
	Other	-	-	-	S,D	-	-	-	-	-	-	-
Algae	**Total**	F,S	F	F	-	-	F	-	-	F,S	-	F
	Macro	-	-	-	-	-	S,D	-	S,D	-	F,S	-
	Turf	-	-	-	-	-	S,D	-	-	-	F,S	-
Ascidians		-	-	-	-	-	-	-	-	-	S	-
Sponges		-	-	-	-	-	-	-	S,D	-	S	-
Other Biota		-	-	-	-	-	F	-	-	S	-	-
Sand/Rubble		-	-	-	-	-	-	-	-	F	-	-
Other Benthos		-	-	-	-	-	S,D	-	-	F	-	F
Unidentified		S	-	-	-	-	-	-	-	F	-	-
Height (cm)		-	-	-	-	S,D	-	-	S,D	-	F,S,D	-
Damage (%)[2]		-	-	-	S,D	S,D	-	-	S,D	S	F,S,D	-

[1] Size structures of populations were also generated.
[2] Damage was either by estimation of the percentage of each colony that was damaged, or later as the percentage of individuals in the population that had been damaged.

Table 3.3 Methods used for benthic monitoring at each pontoon.

Method	Dimension	Pontoon										
Method	**Dimension**	**Agin2d**	**Agin3a**	**Agin4**	**Arlingt^{n}**	**Hardy**	**Kelso**	**Low**	**Mor-GA**	**Mor-SL**	**Norm^{n}**	**Wistari**
Line transect	**20m**	✍	✍	✍		✍			✍		✍	
Video line transect	**20m**	✍										
Video belt transect	**20 x 0.6m**				✍							
	25 x 0.3m						✍					
	25 x 0.6m									✍		
	50 x 0.3m									✍		
	50 x 1m									✍		
	50 x 2m									✍		
Photo quadrat	**1 x 1m**		✍				✍					
Video quadrat	**1 x 1m**	✍										
Manual quadrat	**1 x 1m**						✍					
Photos of tagged corals							✍					
***In situ* estimate - tagged corals**					✍					✍		
Total survey								✍				
Unspecified												✍

Most methods of data collection had been used previously in ecological studies. They were thus ‘standard techniques’ and widely accepted, as seems appropriate for impact assessment studies. Line Intercept Transects were used in six of eleven studies, while video belt transects were used in three further studies (Table 3.3). At Low Isles, a map of all corals under the pontoon was made. It was not possible to determine from the consultant’s final report the method used to collect data at Wistari pontoon. At five pontoons, several methods were used in addition to transects: at Arlington, Kelso and Moore-SL pontoons, tagged individuals were photographed or inspected for damage *in situ*, while at Agincourt 2d and Agincourt 3a pontoons, $1m^2$ quadrats were photographed or videoed (Table 3.3). In several cases, these photographic methods were neither fully analysed nor repeated on later sampling occasions. In the case of one pontoon (Agincourt 2d) this was deliberate: the photographs were taken as a permanent record of the sites, for future reference if required.

3.1.2 Effects of the Pontoon Footprint

The pontoon footprint is the area of substratum directly beneath the pontoon structure. The footprint is shaded by the structure above it and may also be affected by anti-fouling paint, changes in water quality associated with fish aggregations and large numbers of people, and abrasion by anchors and chains. Impacts over the area of the pontoon footprint were studied at eight of the eleven pontoons (Agincourt 2d, Agincourt 3a (two studies), Agincourt 4, Kelso, Low, Moore-SL, Norman and Wistari).

Monitoring of the footprint was generally aimed at detecting the gross effects of the pontoon on corals or documenting change in cover of benthos under the pontoon. No more specific aims, in terms of effect sizes, desirable statistical power, or the target use of the monitoring results, were expressed in any report. There was an implicit assumption evident in most pontoon monitoring documents that shading would be the main cause of impacts on coral cover underneath the pontoons, but this hypothesis was not tested explicitly in any study. In most cases, the possible cause of footprint impacts were not articulated or separated. Whilst the exact cause of an impact might not be of first order interest for management of pontoons, it is important to guard against adoption of untested assumptions of causal factors.

Table 3.4 Designs implemented for monitoring the impacts of the pontoon footprint

Pontoon	# Impact Sites	# Control Sites	# Times Before	# Times After (over period)	# Sample Units / Site
Agincourt 2d	1	2	0	2 (7 yr)	2[3]
Agincourt 3a	1	2	0	2 (7 yr)	2[3]
Agincourt 3a (Removal)	1	4	2	2 (14 mo)	6
Agincourt 4	1	4	2	2 (14 mo)	6
Kelso	1	1	1	0	3
Low Isles	1	0	0	1 (7 yr)	1
Moore SL	1	1[1]	1	2 (15 mo)	6
Norman	1	1	1	1 (13 mo)	5
Norman (Replacement)	1	1	1	1 (13 mo)	5
Wistari	1	2[2]	1	2 (21 mo)	See Table 3.5

[1] For the first sampling event, two controls were sampled. One control site was subsequently 'lost' because of accidental removal of markers.
[2] Only one control site was established for the first sampling event. Subsequently, another control site was added to the design.
[3] Three sampling times at the pontoon site, two at controls

Three of the footprint studies lacked any sampling before the pontoon was installed and one pontoon footprint (at Kelso Reef) was not sampled again after the initial 'pre-impact' survey. In the remaining six studies, baseline surveys were mostly done only once (4 pontoons), a maximum of twice (2 pontoons), and never more than six months prior to installation (Table 3.4). In some cases, baseline surveys preceded the pontoon installation by only one day to one week, apparently mainly because of short notice by the proponent to the Authority (and hence to the consultant) of either the installation, its exact site, or its timing. In some cases it was apparent that internal advice of proposed pontoons was provided to relevant Research and Monitoring staff with very limited lead time before pontoon installation. In general, the level of baseline monitoring was clearly insufficient to provide an indication of temporal variation of variables in the absence of the pontoons.

Three monitoring programmes had only one post-installation survey, six studies had 2 post-installation surveys, and one study (at Kelso Reef) had none. Only two pontoons (Agincourt 3a & 4) had more than one survey both before and after installation. For six pontoons, then, there was only weak or no logical basis from which to infer that an impact had or had not occurred, because of inadequate sampling before and/or after the installation.

The time scale of sampling after installation of the pontoon ranged from 12 months (Norman) to 7 years (Low Isles[1]), with most programmes completed 18 months after the pontoon was installed. This was a very short period compared with natural rates of change in some coral assemblages (*e.g.*, Done 1988), and it was apparently assumed that any impact(s) the pontoon may have had on benthos in the footprint would be sudden and dramatic. Monitoring of pontoon footprints did not allow for assessment of long-term gradual changes in coral assemblages, such as might have occurred if the pontoon footprint altered patterns in recruitment or gradual mortality over long periods of time. This apparent shortcoming may have been a result of monitoring being tied to the duration of the permit to operate a pontoon, with continuation of monitoring beyond that period presumably dependent on successful renewal of such permits. Only one of the programmes reviewed here included studies continued after renewal of a permit (monitoring at Norman Reef). If monitoring is expected to continue after permit renewal, such ongoing monitoring should provide more information about long-term trends in coral assemblages subjected to activities associated with pontoons.

Studies at all eight pontoons had a single impact site (the pontoon) and numbers of control sites varying from none to four (Table 3.4). Several studies suffered from changes in design during monitoring. At Moore-SL, one of two control sites was 'lost' after accidental removal of marker stakes. At Wistari Reef, an additional control site was added to the single control site sampled during the first monitoring event. Hence, Kelso, Moore-SL, Norman and Wistari pontoons only had a single control site monitored both before and after the pontoon was installed. This meant that any differences between the pontoon and control sites could not logically and unambiguously be attributed to the effect of the pontoon because they could equally have been simply a result of natural spatial variation.

Replication of sample units varied from one to six replicates. At Wistari Reef, the sample units were coral outcrops (bommies), many of which were destroyed by movement of the anchor chains and a cyclone. The number of replicates thus decreased over the period of monitoring (Table 3.5). The levels of replication were generally low, and meant that the designs had low power to detect changes at any site. Mundy (1991) concluded that no fewer than 8 line transects were adequate to estimate spatial variability in coral communities.

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[1] The study at Low Isles that consisted of a single survey seven years after the pontoon was installed was not intended to assess damage by the pontoon but to provide a baseline against which further change could be measured.

Table 3.5 Changing sample sizes of footprint monitoring at Wistari Reef

Site	Number of outcrops monitored		
	January 1989	**December 1989**	**October 1990**
Pontoon	12	7	3
Control 1	13	11	4
Control 2	-[1]	10	9

[1] Second control site not established until after pontoon installed

In summary, there was no assessment of the state of the reef prior to the introduction of the impact at three pontoons, and no assessment of natural temporal variation at the impact site prior to installation at four pontoons. One study was uncontrolled, in three studies impact was confounded with spatial variation, small numbers of replicates were sampled at all pontoons, and the duration of monitoring was short compared with rates of natural change in coral communities.

3.1.3 Effects of Snorkelling Activities

Snorkellers could affect benthic communities by breaking corals with their fins or by standing on coral. The effects of snorkelling were studied at seven of the eleven pontoons (Agincourt 2d, Arlington, Hardy, Kelso, Moore-GA, Moore-SL and Norman Reefs). Two separate studies of the impact of snorkellers on benthos were done at Moore-SL and Norman pontoons (Table 3.6). Monitoring the effects of snorkellers generally focussed on designated snorkelling areas near pontoons, where measures of both coral coverage and direct indicators of impact like breakage of corals and changes in coral height and/or width were measured.

Monitoring of coral within snorkelling areas was aimed at detecting changes in coral cover, or more specifically, in later surveys, changes in the proportion of coral colonies damaged. Apart from one report in a series of four on the Moore-SL pontoon which defined an acceptable impact as '[damage] not more than 20% (relative) greater than at unused control sites', no quantitative definition of the magnitude of impacts to be detected was included in any report.

Table 3.6 Designs of monitoring to detect impacts of snorkellers

Pontoon	# Impact Sites	# Control Sites	# Times Before	# Times After (over period)	# Sample Units/site
Agincourt 2d	1	2	0	1 (9 yrs)	9
Arlington	2[a]	1	1	2 (16 mo)	9[a]
Hardy	1	2	1	2 (15 mo)	10
Kelso	1	2	0	1 (17 mo)	3
Moore-GA	1	2	1	2 (15 mo)	5[c]
Moore-SL[b]-1	2	2	1	3 (15 mo)	4
Moore-SL-2	2[d]	1	0	2 (15 mo)	10
Norman	1	1	1	1 (13 mo)	5
Norman (Replacement)	1	1	1	1 (13 mo)	10[e]

[a] After the first sampling event, the design was altered so that the two impact sites (high and low impact) were considered a single site with 16 replicate transects, while the control site contained 11 transects.

[b] Two studies of snorkelling were set up at Moore-SL. For details of the first, see Table 3.7. The second study was established on the third sampling trip, which was the second after the pontoon was established.

[c] Five replicates in each of two habitats

[d] After the first sampling event, the design was altered so that the two impact sites (high and low impact) were considered a single site with 13 transects, while the control site contained 13 transects.

[e] Five replicates from the initial monitoring of installation (1987-8) and five additional transects set up before replacement in 1992

In three studies, no surveys were done before snorkellers started using the pontoon (Table 3.6). This meant that any potential impacts from snorkelling could not be unambiguously attributed to the effects of snorkellers because there was no knowledge of differences between snorkel and control sites before activities had commenced. All other studies included only one sampling event before the pontoon was installed. Sampling after the pontoon was installed was done a maximum of three times (1 study), but 4 studies had only one post-impact survey. The periods between installation and final (or only) surveys ranged from 13 to 16 months in most cases, but up to 9 years at Agincourt 2d pontoon.

There were six studies with one impact site and three studies with two impact sites (Table 3.6). Four studies involved only a single control site, and the remainder had two control sites. For one of the studies at Moore-SL, there was disagreement between successive consultants over whether two sites were ever used for snorkelling, and hence whether they should be considered control or impact sites (Table 3.7). At Arlington and Moore-SL pontoons, studies were set up treating the pontoon as a point source of disturbance, with two impact sites representing high (close to the pontoon) and low (further away from the pontoon) intensity of use by snorkellers. These two impact sites were subsequently merged as there was no evidence of different intensities of use by snorkellers, and some replicates were outside the snorkelling area. At Moore-SL, two separate studies were done on the effects of snorkelling, one of which was later discarded. The discarded study had two impact sites for three of the four sampling events but none at the final monitoring event (Table 3.7).

Replication of sampling units at each site ranged from 3 to 10, but at Arlington and Moore-SL pontoons, the number of replicates changed through the study because of changes in the designation of replicates as belonging to control or impact locations (Table 3.6). The only sampling at Moore-SL before the pontoon was installed consisted of a single transect which was videoed once and later sampled four times to provide 'replicates' for analysis (Table 3.7). These were pseudo-replicates in that only one transect was videoed, so the 'replicates' do not represent independent samples from different locations on the reef or subject to different impact events.

Table 3.7 Changes in the numbers and designations of sites and transects used for monitoring snorkelling impacts at Moore-SL pontoon. The designation of sites A, B, C, D, & E are shown as either **I** (= Impact) or **C** (= Control) for each sampling occasion.

	Site					
Sampling Date	**A**	**B**	**C**	**D**	**E**	**# transects, size**
March 1991 (before installation)	I	I	C	C	-	1 transect, 50 x 2m
October 1991	I	I	C	C	C	4 transects, 50 x 2m
June 1992	I	C	C	C	I[a]	4 transects, 50 x 0.3m
February 1993	C[b]	-	C	-	-	4 transects, 50 x 0.3m

[a] Site 'lost' because of accidental removal of markers
[b] Designated as control because transects outside marked snorkel area, and site not used for snorkelling.

In summary, monitoring of the impact(s) of snorkelling suffered from major design faults including lack of baseline data, lack of temporal replication of baseline data, confounded impact and control sites, inadequate spatial replication, changing numbers and designation of control sites and non-independent replicates. The fact that monitoring was targeted at a specific activity and the variables being measured were clearly related to the most likely form of impact of snorkelling, however, was commendable. Such specifically targeted monitoring is likely to be the most cost-effective mechanism for minimising costs of monitoring in future programmes.

3.1.4 Effects of Resort Diving

Resort divers are unqualified divers who are escorted along a dive trail, closely supervised by a staff member of the pontoon operation. Typically, there are two divers per instructor and the instructor maintains physical contact with the new divers. Because resort divers usually have never dived before, they have poor buoyancy control and are perhaps more likely than experienced divers to damage corals by kicking them.

Resort diving was investigated at five pontoons (Arlington, Hardy, Kelso, Moore-GA and Norman Reefs; Table 3.8). Monitoring of dive trails was aimed at detecting coral damage and changes in coral cover. No more detailed objectives were stated in any report. Survey methods were generally similar for monitoring diving as for monitoring snorkelling.

At Arlington and Kelso reefs, no pre-impact sampling could be done because the position of the dive trail was decided only after the pontoon had been installed and diving had started. At Kelso and Norman reefs there was only one survey done after installation (replacement in the case of Norman) of the pontoon, but at the other reefs two surveys were done after installation of the pontoon, the latest 15 or 16 months after installation (Table 3.8).

Table 3.8 Designs implemented for monitoring the impacts of resort divers at pontoons

Pontoon	**# Impact Sites**	**# Control Sites**	**# Times Before**	**# Times After (over period)**	**# Sample Units/site**
Arlington	1	1	0	2 (16 mo)	1/10[a]
Hardy	1	2	1	2 (15 mo)	10
Kelso	3[b]	0	0	1 (17 mo)	3
Moore GA	1	2	1	2 (15 mo)	5[c]
Norman (Replacement)	1	2	1	1 (15 mo)	5

[a] One replicate at dive site, 10 replicates at control site

[b] Three sites represent frequent, infrequent and very infrequent dive visits. The infrequently and very infrequently visited sites were intended as controls.

[c] Five replicates in each of two habitats.

Of the five studies on the impacts of resort divers on benthic assemblages, one consisted of monitoring at one impact and one control site, three consisted of monitoring at one impact and two control sites, and one had no control sites, but three impact sites (Table 3.8). This study, at Kelso Reef, was set up as a single impact site with two control sites, but the two 'control' sites were found to be subjected to infrequent and very infrequent diving activities and so could not strictly be considered undisturbed controls.

Replication within sites ranged from 3 at Kelso Reef to 10 at Hardy Reef (Table 3.8). At Arlington pontoon, a single long transect along the dive trail was compared with 10 replicate transects at the control site for the first post-installation survey, but 5 replicate transects were sampled along the dive trail on the second survey.

In summary, designs of monitoring for the impacts of resort diving on benthic assemblages were flawed in several ways. No baseline information was collected at two pontoons, and there was no temporal replication in baseline studies at the other three pontoons where diving activities were monitored. One study was uncontrolled, in one study impact/control contrasts and spatial variation were confounded, and replication was generally low. Studies were of short duration compared with the lifetime of the pontoon and with natural rates of change in coral communities, though too infrequent to document adequately the rates of breakage and/or healing of corals.

3.2 Monitoring Fish Assemblages

Aggregations of fish were consistently associated with, and monitored at, all pontoons. Concern over the presence of large aggregations of fish at pontoons mainly related to the potential for them to affect local populations of fish by depleting populations in surrounding areas, either through movement of fish away from their original habitats to the pontoon site or by increasing the risk of predation on small fish in the vicinity of the pontoon. The main objective of monitoring fish populations at all pontoons was to estimate the effect of the pontoon on the abundance and composition of fish assemblages at the pontoon and at control areas. A subsidiary aim of most monitoring programmes was to determine whether the pontoon aggregation had any effects on fish populations elsewhere on the reef. The effects of interest were whether aggregations of predatory fish affected the local abundance of site-attached fish, and whether the accumulation of fish at the pontoon led to a decline in abundances elsewhere on the reef (the ‘depletion effect’). Monitoring programmes were not designed to test cause-effect inferences and so conclusions about the ‘depletion effect’ of fish aggregations could be based only on correlation (but see experimental work by Sweatman 1996).

Table 3.9 Variables monitored in assessing impacts of pontoons on fish assemblages.

Family	Pontoon										
	Agin2d[a,b]	**Agin3a[a,c]**	**Agin4[a,c]**	**Arlingt[n]**	**Hardy**	**Kelso**	**Low[a]**	**Mor-GA**	**Mor-SL**	**Norm[n]**	**Wistari[a,d]**
Acanthuridae	✍				✍	✍		✍	✍	✍	✍
Apogonidae							✍				
Caesionidae	✍			✍	✍	✍	✍	✍	✍	✍	✍
Carangidae					✍	✍	✍	✍		✍	✍
Chaetodontidae	✍	✍	✍		✍		✍	✍		✍	✍
Ephippidae					✍			✍		✍	✍
Haemulidae	✍	✍	✍	✍	✍		✍			✍	✍
Kyphosidae		✍	✍		✍					✍	✍
Labridae				✍	✍		✍	✍		✍	
Lethrinidae	✍	✍	✍	✍	✍	✍	✍		✍	✍	✍
Lutjanidae	✍	✍	✍	✍	✍		✍	✍	✍	✍	
Mullidae											✍
Nemipteridae				✍		✍					✍
Pomacentridae		✍	✍	✍		✍	✍				
Scaridae	✍	✍	✍	✍	✍	✍	✍	✍	✍	✍	
Scombridae											✍
Serranidae	✍	✍	✍	✍	✍	✍	✍			✍	✍
Siganidae	✍				✍			✍	✍	✍	✍

[a] Individual species representing these families were counted but not necessarily all species that occurred at the pontoon.

[b] Fifteen species were targeted during sampling in 1987 and 1989, but all fish encountered were recorded in 1993.

[c] Twenty-three species were targeted for counting.

[d] Fish were categorised into four groups: Benthic Feeders, Herbivores, Mid-Water Feeders and Miscellaneous. Benthic Feeders included Acanthurids, Chaetodontids, Labrids, Serranids, Lethrinids, Acanthurids, Mullids, Haemulids and Nemipterids; Herbivores included Kyphosids and Siganids; Mid-Water Feeders included Carangids, Caesionids, Ephippids and a Scombrid; and Miscellaneous included Rays, Remora and Scarids.

The variables measured for assessing the impacts of pontoons on fish assemblages were relatively comparable across all pontoons except Wistari pontoon. At most pontoons, all species were counted and grouped into family groupings (Table 3.9). At Wistari pontoon, species were grouped into broad categories: benthic feeders, herbivores, Scarids, mid-water pelagics and miscellaneous. These categories included some unlikely and ecologically diverse groupings: benthic feeders included Acanthurids, Chaetodontids, Serranids, Lethrinids, Mullids, Haemulids and Kyphosids; mid-water feeders included Carangids, Scombrids, Caesionids and Ephippids; and herbivores included Kyphosids and Siganids. Monitoring at Agincourt reefs focussed on target species, excluding some groups that were found to be affected by other pontoons.

The most common method of data collection was by counting along belt transects (Table 3.10). At pontoons at Kelso, Moore-SL and Wistari reefs, rapid visual surveys were used (Table 3.10). This method was replaced by belt transects eight months after the pontoon was installed at Moore-SL pontoon (Table 3.10).

Both of these methods imposed difficulties in data analysis. Rapid visual surveys involved timed counts over an arc of 180^o and a radius of a given (estimated) length. It is difficult to avoid counting repeatedly over the same area of substratum, especially in a confined area such as the area under a pontoon. This means that there is a high probability that counts intended as spatial replicates for a comparison between control and impact sites are non-independent. Counting aggregated fish on a belt transect under the pontoon and comparing with counts of non-aggregated fish at control sites also poses problems because the data collected at the different sites will have different distributions and variances. More specifically, counts under the pontoon are likely to be highly non-normal. The biological interpretation of a comparison between aggregated fish at a pontoon with non-aggregated fish elsewhere is not clear. These issues are not addressed in the pontoon monitoring reports.

Table 3.10 Methods used for monitoring fish abundances in pontoon monitoring programmes

Method	Dimension	Pontoon										
		Agin2d	**Agin3a**	**Agin4**	**Arlingt^{n}**	**Hardy**	**Kelso**	**Low**	**Mor-GA**	**Mor-SL**	**Norm^{n}**	**Wistari**
Belt transect	30 x 7.5m		✍	✍								
	50 x 6m							✍				
	50 x 10m				✍					✍		
	50 x 20m	✍				✍			✍		✍	
Rapid Visual Count	180^{o} arc, 5m radius						✍					
	180^{o} arc, 10m radius									✍		✍

At Hardy, Low, Moore-GA and Moore-SL pontoons, no statistical analyses were done. Analysis of fish counts at other pontoons was by various analysis of variance models. The design of monitoring at Arlington pontoon was so inconsistent methodologically, and changes so confounded with the installation of the pontoon, that the data were not usefully analysable. Repeated measures analyses of variance comparing variation among sites were used to analyse data from pontoons at Agincourt 2d, 3a and 4, Norman and Wistari reefs, but the models used did not specifically test for an impact (*ie* all sites were compared, rather than Impact *vs* Controls). It should be noted, however, that many of the monitoring programmes pre-dated the emphasis on asymmetric analyses seen in recent monitoring literature (*e.g.* Underwood 1991, 1993).

At the Agincourt pontoons, there was considerable effort put into verifying the tidal and diurnal related variations in fish numbers at pontoon and control sites. This was a good example of the combination of impact monitoring with research in the situation where observers had frequent access to reef sites.

At two pontoons, no surveys of fish were done before the pontoon was installed. At seven pontoons, only one survey was done before the pontoon was installed or replaced but at two of these seven pontoons (Wistari and Norman replacement), fish counts were done two times separated by a month within the same sampling event (Table 3.11). Sampling after the pontoon was installed continued for up to 8 years (Agincourt 2d), but most studies were completed within 18 months (Table 3.11), and included only 1-3 surveys. The fish surveys at Agincourt 3a and 4 pontoons were perhaps the most adequate of all components of the monitoring programmes with respect to spatial and temporal replication, having two pre-installation and six post-installation surveys at the pontoon sites and four control sites.

Monitoring of fish assemblages took place at one impact and multiple control sites at all pontoons except Norman pontoon (1987-88), where one of the ‘control’ sites was used by another tourist operation and also had an aggregation of fish associated with it (Table 3.11). Apart from monitoring at Norman Reef pontoon, the number of control sites varied from two to four.

Table 3.11 Designs of monitoring programmes intended to detect impacts of pontoons on fish.

Pontoon	# Impact Sites	# Control Sites	# Sample Units/site	# Times Before	# Times After (over period)	# Months / Time	# Days / Time
Agincourt 2d	1	2	4[a]	0	3 (9 yr)		5[b]
Agincourt 3a (Removal)	1	4	2	2	6 (12 mo)		
Agincourt 4	1	4	2	2	6 (12 mo)		
Arlington	1	3	5[c]	1	3 (16 mo)		3
Hardy	1	3	1	1	2 (15 mo)		3
Kelso	1	2	15	0	1 (17 mo)		
Moore GA	1	2	2[c]	1	2 (15 mo)		3
Moore SL[d]	1	3	5[c]	1	3 (15 mo)	2	3[e]
Norman	2	1	5	1	1 (13 mo)		
Norman (Replacem[t])	1	2	5	1	2 (12 mo)	2	3
Wistari	1	3	3	1	2 (37 mo)	2	3[e]

[a] Four replicates at control sites but only three replicates at impact site.
[b] Two separate reports on monitoring at Agincourt 2d disagree on the design of fish monitoring. In the first report (Richards 1992), no replicate days were sampled and there were only three replicate counts at all sites. The second report (Marine Environmental Monitoring 1993) claims that each of the spatial replicates were sampled on each of five consecutive days.
[c] One replicate under the pontoon.
[d] See Table 3.9 for details about changes in the design of fish monitoring at Moore SL pontoon.
[e] Transects sampled twice a day on each replicate day for at least one sampling event.

Sampling replication ranged from one sample unit per site at Hardy Reef to 15 at Kelso Reef (Table 3.11). These 15 replicates were unlikely to be independent under the pontoon because of the limited space available to sample in the pontoon footprint. At Moore-GA pontoon, one sample unit was surveyed under the pontoon and compared with two replicates at control sites. At seven of the ten pontoons, sample units were surveyed repeatedly over consecutive days. These repeat surveys were considered as independent replicates in most analyses, although they were temporal 'pseudo-replicates' rather than legitimate random, independent replicates, and not appropriate for spatial comparisons between control and impact locations. It was likely also that the repeated surveys of the same or closely spaced units on successive days would be highly correlated for at least some fish taxa, though this was not examined in most studies. In a number of the analyses, these repeat samplings were not treated as repeated measures (even though the sites were repeatedly sampled). There were several cases where statistical tests were incorrectly done, specifically by using the incorrect error terms in F-tests. These errors were apparently not flagged by reviewers and persisted to the final reports.

There were changes in the design of monitoring at Arlington and Moore-SL pontoons. At both pontoons, replicate transects were surveyed at the impact site before the pontoon was installed, but after installation, only one count of all fish under the pontoon was done. This change in method confounded the comparison between pre- and post-impact with changes in methodology and also meant that comparisons between control and impact sites over time were confounded and analytically problematic (because of unbalance in the repeated measures model). Changes in the design of monitoring of fish assemblages at Moore-SL were complex (Table 3.12). One count was done before installation and was intended as one of a pair of counts, but the second count was done after installation. Eight months after installation, one control site had been moved, both spatial and temporal replication had changed, and replicate times within the sampling event were separated by two months (Table 3.12). For the final survey, repeat samples were separated by one month (Table 3.12). These changes in design confounded comparisons between control and impact sites and through time because there was no straightforward way of partitioning differences that were due solely to changes in design and differences that were a result of an impact by the pontoon. These issues were not resolved in any of the reports on monitoring at Moore-SL.

Table 3.12 Changes in the design of sampling programmes for monitoring fish populations at Moore-SL pontoon

Sampling Event	# Impact Sites	# Control Sites	# Sample Units/site	# Times of Day	# Days	# Months / Event
Baseline	0	0	0	0	0	0
Installation	1	3	6	2	4	2[a]
8 months	1	3[b]	5[c]	1	3	2[d]
15 months	1	3	5[c]	1	3	2[e]

[a] One count taken before installation of the pontoon and one count done a month after installation.
[b] One control site decommissioned and another established closer to the pontoon.
[c] Five replicates at control sites but only one replicate at the pontoon (impact) site.
[d] Counts done two months apart.
[e] Counts done one month apart.

Monitoring of spatial and temporal patterns in abundances of fish thus suffered from a number of design faults. Baseline studies were inadequate because of lack of temporal sampling. This was particularly important for fish because of the temporal variability in their abundances (Richards 1992, Sale & Douglas 1984). At four pontoons, there was no spatial replication within the impact site, although there was at control sites. This suggested that either the scale of impact and control sites differed, or the sizes of sampling units differed between impact and control sites (or both). Either variation would mean that comparisons between impact and control sites were confounded with at least one other variable that would be expected to influence counts of fish (Mapstone & Ayling 1993). At three of these pontoons, counts on separate days were intended as replicates but those counts were apparently non-independent in space or time. In addition, they were not appropriate replicates for spatial comparisons between impact and control sites. At one pontoon, natural variation among sites was confounded with impact status (*ie* there was only one control site). Changes in design at two pontoons were also confounded with impact status because the changes occurred at the same time as the pontoon installation.

3.3 Monitoring of Water Quality

Water quality data were collected at pontoons at Agincourt 2d (1987-1989), Agincourt 3a (removal), Agincourt 4, and Moore-SL Reefs.

At Moore-SL and Agincourt 2d, data were collected only once. The purpose of these single samples was 'to provide an indication of the relative nutrient status of Moore Reef' and to provide 'baseline levels of nitrogen and phosphate in an area of concentrated tourist activity' (at Agincourt 2d). The aim of sampling at Agincourt 3a was to determine 'whether the removal of the large scale tourist operation significantly changed nutrient levels', and at Agincourt 4 'whether anthropogenic inputs of nutrients associated with the tourist operation significantly increased nutrient levels [...] above normal fluctuations'.

Three variables were common to all four studies: Orthophosphate, Ammonia, and Nitrate (Table 3.13). The nutrients most likely to change in response to a pontoon are orthophosphate (from bird guano) and ammonia (from human urine). Characterisation of the composition of water was more detailed at Moore-SL, with nine variables measured. These variables were also commonly measured in other studies on water quality (*e.g.*, Steven *et al.* 1989, Furnas *et al.* 1995).

Table 3.13 Water quality variables measured when monitoring impacts of pontoons.

Variable	Aginc^{t} 2d	Aginc^{t} 3a, 4	Moore-SL
Chlorophyll-a			✓
Particulate Organic Nitrogen			✓
Particulate Organic Phosphorus			✓
Orthophosphate	✓	✓	✓
Ammonia	✓	✓	✓

Silicate			✍
Nitrite		✍	
Nitrate	✍	✍	
Nitrite + Nitrate			✍
Total Dissolved Nitrogen			✍
Total Dissolved Phosphorus			✍

No analysis was possible for data collected from Agincourt 2d pontoon. One-way analyses of variance were used to test for differences among sites in the Moore-SL reef study, while three way analyses of variance (factors: Reef, Site(Reef), Time) were used to analyse data from monitoring at Agincourt reefs. No multivariate analyses were done.

At Agincourt 2d pontoon the only sampling occurred five years after the pontoon was installed and operational, so did not represent a 'baseline'. At Moore-SL pontoon, sampling occurred only before the pontoon was installed and did not include the intended pontoon site, so was not useful for assessing impacts. Water quality was sampled twice before the pontoon was removed from Agincourt 3a and installed at Agincourt 4 reef, and twice after relocation (Table 3.14).

There were no control locations sampled at Agincourt 2d pontoon and no impact site at Moore-SL. The study at Agincourt 3a and 4 pontoons, however, had several control sites, with three control sites sampled on the reefs supporting the pontoons and four control sites on Agincourt 1 reef (where there was no pontoon) (Table 3.14).

Table 3.14 Designs of water quality sampling programmes associated with pontoon monitoring.

Pontoon	# Impact Sites	# Control Sites	# Times Before	# Times After	# Samples /Site/Time
Agincourt 2d	1	0	0	1	5[a]
Agincourt 3a & 4	1	7[b]	2	2	3
Moore-SL	0	6[c]	1	0	2

[a] Water samples were taken on five non-consecutive days in different months. One sample was taken next to the pontoon on each day.
[b] Three control sites were on the same reef as the impact site while a further four control sites were situated on Agincourt 1 Reef.
[c] Six sites were distributed over three habitats: 3 lagoon sites, 2 back reef sites and 1 front reef site. None of the sites was near the pontoon, which was moored on the back reef.

Replication was low in all studies. A single sample was taken on each of five days irregularly spaced over two months at Agincourt 2d reef. Two samples from each site were taken for the Moore-SL study and at the Agincourts, three samples were taken at each site. Previous work on water quality on the GBR has shown that nutrients in sea water vary at spatial scales of 100s of metres within one location (Steven *et al.* 1989) up to kilometres across and along the continental shelf (Furnas *et al.* 1995, 1996).

In summary, monitoring of water quality at Agincourt 2d and Moore-SL pontoons was not useful for assessing whether the presence of pontoons affected water quality. The study at the Agincourt reefs had all the elements of a good monitoring design, but replication of sample units was perhaps too small to adequately characterise the highly variable water quality at each site.

3.4 Statistical Analyses

Univariate analysis of variance (ANOVA) was used to test for impacts in most monitoring programmes. No analysis was done on data collected at Low Isles (and none was needed). Apart from analysis of results from Agincourt 2d in the 1995 report (Marine Environmental Monitoring 1995), however, analytical models were generally not those most appropriate for the detection of impacts and/or the data in hand, and in some cases were flawed. For example:

?? Data from Kelso reef were analysed by one-way ANOVA comparing percent cover across sites. The design and analysis was inappropriate for monitoring footprint impacts because there was only one survey of one impact and one control site before installation of the pontoon.

?? Analysis of data collected in 1987-8 on the impacts of installing the pontoon at Norman Reef was by 101 t-tests, with no adjustment of the critical significance criterion to keep the overall error rate to what was expected (? =0.05). With a Bonferroni adjustment, the critical value of ? should have been 0.0005 (Day & Quinn 1989). After monitoring the effects of replacing the Norman Reef pontoon, the entire data set (1987-1992) was analysed appropriately with a repeated measures model, though still not by a model tailored to the detection of impacts (Green 1989, Underwood 1991).

?? The results of monitoring at Wistari pontoon were analysed with a multifactorial ANOVA with time as one of the independent factors. The data were collected as a repeated measures design, but there was no consideration in the analyses of the temporal correlations that characterise repeated measurements.

?? Repeated measures analyses of variance were used in most other studies, but the models used tested for any differences among sites, without regard to their ‘impact’ or ‘control’ status. Thus, they did not explicitly test for ‘Impact *vs* Control’ differences. In the models used, a significant 'Site' or 'Site*Time' effect could have resulted from differences between only control sites as well as a difference between the impact site and one or more control sites. This meant that the inference of impacts hinged mainly on the post-analysis separation of means by methods such as Student-Newman-Kewls (SNK) tests, which were likely to be less powerful than the appropriate F-test in an ANOVA. In some cases, the origin of significant site or Site*Time effects was not examined formally (*e.g.*, by SNK tests) (Table 3.15).

?? The error terms used in various statistical models were incorrect. The most common form of mistake was to test fixed effects of interest in mixed model analyses (with or without repeated measures) against residual variances, when they should have been tested against other terms in the models. The correct tests would have had fewer degrees of freedom (usually far fewer), and considerably lower statistical power. Statistical power was generally not calculated for non-significant results, although the low degrees of freedom for most (correct) tests and the considerable variability in the data would result in very low power tests.

?? The statistical treatment of sampling times and/or sites sometimes varied between analyses within reports. For example, sites would apparently be considered fixed effects for analyses of benthos, but the same sites were treated as random variables when fish data from them were analysed. There seemed to be confusion at times between the meaning of a 'fixed effect' and sampling a 'fixed site or transect', which usually meant taking repeated measurements.

Table 3.15: Ways in which differences between control and impact sites were resolved in reports. **SNK** - Student-Newman-Kewls tests; **n/a** - not applicable; **no** - no formal procedure.

Pontoon	Footprint	Snorkel	Dive	Fish
Agincourt 2d	n/a[1]	n/a[1]	-	Tukey's HSD
Agincourt 3a	SNK	-	-	SNK
Agincourt 4	SNK	-	-	SNK
Arlington	-	n/a[2]	n/a[2]	n/a[3]
Hardy	-	no	no	n/a[4]
Moore GA	-	no	no	n/a[4]
Moore SL	n/a[3]	n/a[3]	-	n/a[3]
Norman	no	no	no	no
Wistari	no	-	-	no

[1] Analysis already tested specifically for impact.
[2] Only one control site; post hoc tests not needed.
[3] Design flaws rendered the data unanalysable.
[4] No analysis was done

Hence, statistical analyses were compromised in a number of ways. First, there were no unambiguous tests for impacts except at Agincourt 2d after 1993. Ambiguity arose from two sources: i) sampling designs which were confounded because there was only one control site and/or one sample before and after installation, and ii) analytical models in which tests were made only for differences among sites, without clear discrimination of which sites differed. Second, assumptions of analyses were often either ignored or violated, or incorrect error terms were used for hypothesis tests, usually because the repeated-measurements in monitoring were treated as random independent measurements over all times. Third, many of the statistical tests were incorrectly constructed, and the results were thus likely to be misleading. Interestingly, many of these errors were not detected by reviewers of draft reports.

No study investigated community-level patterns using multivariate techniques, despite the multivariate nature of all data sets collected (many taxonomic variables collected in the same place at the same time from the same sampling units). We have not attempted to fill this gap.

IV. RESULTS OF MONITORING PONTOONS

4.1 Overview of Consultants' Conclusions

Consultants concluded that impacts of pontoon installations and/or associated activities had occurred at most pontoons (Table 4.1). In some cases, the evidence supporting the conclusions can be considered only circumstantial because of the design and/or analysis faults discussed in the previous section. In general, however, those tentative conclusions of impact were consistent with conclusions from other, better designed, studies. We summarise below the conclusions made by consultants, taken at face value and without reference to their basis in statistical tests. We later consider the statistical basis of the conclusions.

Table 4.1 Summary of consultants' conclusions about the impacts of pontoons or associated activities on benthos and fish assemblages. **yes** - impact inferred; **no** - no impact inferred; **yes/no** - impact on some groups or at some times, but not others; **-** - not studied.

	Benthos			
Pontoon	**Footprint**	**Snorkel**	**Dive**	**Fish**
Agincourt 2d	yes	yes	-	yes
Agincourt 3a	yes	-	-	yes
Agincourt 4	yes	-	-	yes
Arlington	-	yes	yes	yes
Hardy	-	yes	yes	yes/no
Moore GA	-	no	yes	yes/no
Moore SL	no	no	-	no
Norman	yes	no	no	yes
Wistari	yes	-	-	yes

Impacts of pontoon footprints were inferred where coral cover decreased over time at the impact site. In the case of Agincourt 2d, there were no 'before' data, but cover decreased greatly between 1987 and 1993. At Agincourt 3a, coral cover decreased after the removal of the pontoon, and the consultants suggested that it may have been because corals had acclimated to the lowered light regime under the pontoon. Coral cover decreased at Agincourt 4 and Norman pontoons after the pontoons were installed. At Norman pontoon, coral cover decreased after initial installation, stayed relatively constant between 1988 and 1992, then decreased again when a larger pontoon was installed in 1992. At Moore SL, cover decreased under the pontoon, but no more than at the control site and so no impact was inferred. At Wistari pontoon, movement of anchor chains resulted in loss of 9 of 12 marked bommies under the pontoon. This loss was not detected in the consultant's statistical analysis, possibly because analyses were done only with data from the remaining outcrops.

Consultants concluded that snorkelling had no detectable effects at either of the Moore Reef pontoons or Norman pontoon. At Hardy pontoon, coral cover increased as much at impact as at control sites, but levels of damage were greater in the snorkelling area than elsewhere, leading to the inference of an impact. Similarly, at Arlington pontoon, there were no detectable differences in coral cover at impact & control sites, but damage was greater at the impact (snorkelling) site than at control sites. Data from Agincourt 2d were from one time only and showed that levels of damage were greater and coral cover was less on the snorkelling bommie than at control sites.

Resort divers were associated with negative effects on benthos at Arlington, Hardy, and Moore-GA pontoons. At Arlington, coral cover increased at the control site but not along the dive trail, but coral cover was low in both places. The consultant considered the observed impact to be unimportant. At both Hardy and Moore-GA pontoons, damage was greater on dive trails than at control sites, but there were no differences among sites in levels of damage at Norman reef.

All pontoons had associated with them fish aggregations of some sort, which differed from control sites. At Agincourt 2d, large predators were most abundant at the pontoon site, while Chaetodontids and Scarids were less abundant at the pontoon than elsewhere. The consultants suggested that the decrease in coral cover under the pontoon may have contributed to the low abundance of these families. At Agincourt 3a, the number of predators declined after removal of the pontoon until there was no difference between the pontoon and control sites at the end of the study. At Agincourt 4, Wistari, Arlington, Hardy and Norman pontoons, the abundances of predators increased after the installation of the pontoon. At Hardy, the aggregation decreased in size when fish feeding was scaled down. There were no detectable effects of the pontoon aggregations on small fish. At Wistari, the consultants claimed that the aggregation at the pontoon was associated with depletion of populations elsewhere, but reanalysis of the raw data failed to support that conclusion (Sweatman 1996). At Moore-SL, where fish feeding was not done, the numbers of Caesionids, Mullids and Kyphosids increased dramatically with the installation of a new pontoon. Composition of the fish aggregation changed over time at Norman and Agincourt 4. None of the consultants linked the installation of a pontoon to mortality of fishes locally, and most inferred that the effects of pontoons were restricted to effects on the behaviour of some species.

4.2 Benthic Assemblages

4.2.1 Effects of Pontoon Footprints

The effects of the pontoon footprint were investigated at Agincourt 2d, 3a and 4, Moore-SL, Norman and Wistari pontoons. Quantitative data were collected at Kelso Pontoon but only at one time, and the corals in the vicinity of the pontoon at Low Isles were mapped in June 1993. Original analyses detected significant Site*Time interactions which might have indicated impacts at Agincourt 2d, 3a and 4, Moore-SL and Norman pontoons (Table 4.2).

Reanalysis of the same data testing specifically for differences between the pontoon and controls was only possible for monitoring programmes at Agincourt 3a and 4 pontoons because there was only one control site at Moore-SL and Norman pontoons, and we were unable to re-analyse the data from the Wistari pontoon because critical information about which data were repeated measurements of which sampling units was missing from the files we were given. Results of the re-analyses indicated no significant impacts of the pontoons at Agincourt 3a and Agincourt 4, but the tests were not powerful with only 2 and 6 degrees of freedom (Table 4.3; see appendix 1). The non-significant results of the tests are therefore only weak evidence that impacts had not occurred.

Trends in mean coral cover indicated that the pontoon footprints may have been impacting on benthic assemblages. Most coral groups showed changes in percent coverage at pontoon sites that were similar to or more negative than those at control sites (Table 4.4). Exceptions to this general trend occurred at Agincourt 2d (Pocilloporids), Agincourt 4 (Acroporids), Moore-SL (total hard coral, Pocilloporids), and Wistari (total hard corals) (Table 4.4). Averaged over all studies, pocilloporids were the only family to show an annual increase in coverage under pontoons (0.1%), though that increase was the same as that at control sites (0.11%). All other groups of corals showed overall decreases of 0.69-2.88% at pontoon sites but, except for Poritids, remained static or increased slightly (0.11-0.69%) at control sites (Table 4.4). In most cases, the averages for the pontoon sites were influenced greatly by one or two values that were far greater (or less) than the others: Agincourt 4 for total hard corals, Acroporids, and Poritids; Moore-SL for Acroporids Pocilloporids, and Faviids; and Wistari for soft corals (Table 4.4).

It is interesting that after the removal of Agincourt 3a pontoon, coral cover decreased by 2.4% per year. The consultants suggested that the coral had become acclimated to the reduced levels of light under the pontoon and suffered from excess light after it was removed.

In summary, the monitoring programmes we reviewed in which some form of BACI assessment was possible (albeit with only single control sites in some cases), suggested that corals of all families measured performed slightly worse under pontoons than at control sites. The trend was not statistically significant for any group, however (Table 4.5).

4.2.2 Impacts of Snorkelling Activities

Consultants' analyses of the effects of snorkelling activities on corals indicated potential impacts at three of the seven pontoons where snorkelling was monitored (Agincourt 4, Hardy, and Moore-GA pontoons; Table 4.6). These tests indicated that there were differences in the temporal behaviour of coral cover at different sites, but were ambiguous tests of impacts. The only potential impact that remained significant after our re-analyses was the difference in levels of damage at impact and control sites at Hardy Reef (Table 4.7, see appendix 2). Damage (% of individuals that were damaged) was about 7 times as great at the impact site as at the control sites. Our statistical tests, however, were low in power and thus may have missed real impacts.

Trends in mean cover, damage and height of corals showed that the potential impacts of snorkellers varied greatly among pontoons. Cover of hard corals decreased at snorkel sites at Agincourt 4 (1.2% pa) and Arlington (1.3% pa) reefs, while cover at control sites increased by about 1% pa at both reefs. In contrast, coral cover increased in snorkel areas at Hardy (5.5% pa), Moore-GA (13.3% and 8% pa), Moore-SL (14% pa) and Norman (3% pa) reefs (Table 4.8). These increases were greater than increases at control sites by a factor of up to 11 times (at Norman reef, Table 4.8). On average, the increase in coral cover at impact sites was approximately 1% per annum greater than at control sites and were due largely to increases in cover of Acroporids. Cover of Pocilloporids increased marginally more at impact sites than at control sites on average (by 0.23% pa), as did cover of Faviids (0.2% pa compared with a decrease of 0.07% pa at control sites, Table 4.8), but other families did not grow as well at impact sites as at control sites (Table 4.8). Levels of damage increased at impact sites relative to controls at all pontoons except that at Norman reef. Averaged across all pontoons, coral heights increased in snorkelling areas by 12 cm per year, compared with an increase of 0.86 cm per year at control sites, but this estimate was biased by large increases in height at Moore-GA snorkelling area. At other pontoons, and in the Acropora thicket at Moore-GA, heights decreased in the snorkelling area (Table 4.8). Statistically, there were no differences between changes at impact and control sites for any variable (Table 4.9). This is not surprising because of the variability associated with the means (Table 4.9).

Table 4.2 Results of consultants' tests for impacts of pontoon footprints on % coral cover of taxa indicated (Site*Time terms only) from original analyses. Figures in bold indicate significant results.

	Hard Corals		Acroporids		Pocilloporids		Faviids		Poritids		Soft Corals	
Pontoon	**F**	?	**F**	?	**F**	?	**F**	?	**F**	?	**F**	?
Agin2d[a]	**9.8**	**<0.05**	**11.5**	**<0.05**	0.1	>0.05	0.1	>0.05	0.6	>0.05	0.3	>0.05
Agin3a[b]	2.11	>0.05	2.20	>0.05	1.46	>0.05	**2.38**	**<0.05**	**3.20**	**<0.05**	0.75	>0.05
Agin4[b]	**2.51**	**<0.05**	0.97	>0.05	0.74	>0.05	1.93	>0.05	**2.45**	**<0.05**	0.84	>0.05
Mor-SL[c]	**6.34**	**0.01**									0.41	0.67
Norman[d]	7.77	0.26	**13.47**	**0.005**	0.56	0.65	1.31	0.30	0.25	0.86	0.39	0.76
Wistari[e]	0.56	>0.05									2.50	>0.05

[a] Test for impact at Agincourt 2d compared variation in the proportional difference in % cover on benthic transects in 1987 and 1993 among transects underneath the pontoon with variation among transects beside the pontoon and at control sites. Test had 1,6 df.

[b] Degrees of freedom = 8,50

[c] Degrees of freedom = 2,20

[d] Degrees of freedom = 3,24

[e] Degrees of freedom = 2,183

Table 4.3 Results of re-analyses testing for impacts of pontoon footprints on % coral cover of taxa indicated (Impact*Time terms only shown, for full details see Appendix 1).

	df	Hard Corals		Acroporids		Pocilloporids		Faviids		Poritids		Soft Corals	
Pontoon		**F**	?	**F**	?	**F**	?	**F**	?	**F**	?	**F**	?
Agin3a	2,6			1.22	0.36	0.04	0.96	0.41	0.68			0.89	0.46
Agin4	2,6	0.61	0.58	0.24	0.80	0.37	0.71	2.56	0.16	0.57	0.60	2.26	0.19

Table 4.4 Summary of effects of pontoon footprints. Data were mean annual changes in percent coverage at impact and Control sites for indicated taxa. Where more than one control site was monitored, data were averaged across control sites.

	Hard Corals		Acroporids		Pocilloporids		Faviids		Poritids		Soft Corals	
Pontoon	**impact**	**control**	**impact**	**control**	**impact**	**control**	**impact**	**control**	**impact**	**control**	**impact**	**control**
Agin2d	-1.94	1.24	0.04	2.05	0.03	-0.04	-0.39	0.23	-0.29	-0.26	0.05	0.07
Agin3a	-2.39	2.63	-0.42	0.53	-0.71	-0.03	0.49	1.15	-0.92	0.86	-0.02	0.44
Agin4	-10.96	-1.33	-1.26	-2.97	-0.50	0.06	-0.12	0.29	-8.94	-0.91	0.16	0.21
Mor-SL	-0.73	-4.21	-1.81	0.72	1.67	1.17	-3.38	2.67	-	-	-0.68	0.13
Norman	-2.09	3.19	-0.65	6.21	0.03	0.16	-0.06	0.06	-1.35	-1.13	-0.11	0.02
Wistari	2.15	0.09	-	-	-	-	-	-	-	-	-15.10	-0.66
MEAN	-2.66	0.60	-0.82	0.20	0.10	0.11	-0.69	0.69	-2.88	-0.21	-2.61	0.11

Table 4.5 Comparisons of mean change in % coral cover at 4 impact locations (Agincourt 4, Moore-SL, Norman, Wistari) with mean change at corresponding control locations. Means were compared by t-tests (t, df, ?$_t$), after first testing for homogeneity of variance (F, ?$_h$). Degrees of freedom for the t-tests were adjusted where ?$_h$<0.05. Figures in bold indicate significant results.

	Impact			Control			Variances		t-tests		
Variable	**Mean**	**n_i**	**SE_i**	**Mean**	**n_c**	**SE_c**	**F**	**?$_h$**	**t**	**df**	**?$_t$**
Hard coral	-2.91	4	2.83	-0.77	8	0.98	4.19	**0.05**	-0.9	10	0.39
Acroporids	-1.24	3	0.34	-0.83	6	1.84	60.59	**0.02**	-0.22		0.83
										5.3	
Pocilloporids	0.4	3	0.65	0.26	6	0.22	4.4	0.07	0.26	7	0.80
Faviids	-1.19	3	1.10	0.65	6	0.5	2.4	0.19	-1.79	7	0.12
Poritids	-5.15	2	3.81	-0.95	5	1.14	4.45	0.10	-1.52	5	0.19
Soft coral	-3.93	4	3.73	-0.04	8	0.20	175.3	**0.00**	-1.04	3	0.37

Note: Some Standard Errors appear greater than the respective means. This arises because the data from which both were calculated were signed, and hence not bounded by zero.

Table 4.6 Results of consultants' tests for impacts of snorkelling on % coral cover and damage, and mean heights of corals (Site*Time only) from original analyses. The **(Ac)** for the Moore-GA pontoon indicates data from a snorkelling site dominated by *Acropora* thickets, that were treated differently from other data. Figures in bold indicate significant results.

	Hard Corals		Acroporids		Pocilloporids		Faviids		Poritids		Soft Corals		Damage		Height	
Pontoon	**F**	?	**F**	?	**F**	?	**F**	?	**F**	?	**F**	?	**F**	?	**F**	?
Agincourt 4[a]	1.83	>0.05	**3.04**	**<0.05**	1.39	>0.05	**1.67**	**<0.05**	0.66	>0.05	0.79	>0.05				
Arlington[b]	2.07	0.14									1.48	0.24				
Hardy[c]	2.41	0.08	**4.45**	**0.009**	1.34	0.27	0.54	0.71	2.45	0.06	0.39	0.74	**12.29**	**<0.001**	**5.36**	**0.002**
Moore-GA[d]	2.92	0.05	2.87	0.05	2.08	0.13	0.43	0.75	**3.91**	**0.02**	1.23	0.33	1.26	0.32	**5.08**	**0.005**
Mor-GA[d] **(Ac)**	0.74	0.57	0.63	0.61	0.27	0.89	1.54	0.23	0.18	0.89	**5.06**	**0.01**	1.93	0.15	1.99	0.17
Moore-SL[e]	1.58	0.22	0.01	0.94	2.41	0.13	0.39	0.54	0.09	0.76	0.25	0.62				
Norman[f]	2.36	0.14	1.43	0.25	0.09	0.77	1.16	0.30	0.97	0.34	1.93	0.18	0.002	0.96	0.18	0.68

[a] 8,50 df; [b] 2,50 df; [c] 4,54 df; [d] 4,24 df; [e] 2,12 df; [f] 1,18 df

Table 4.7 Results of re-analyses testing for impacts of snorkelling on cover of corals, levels of damage and colony heights (Impact*Time terms only shown, for full details see Appendix 1). The **(Ac)** for the Moore-GA pontoon indicates data from a snorkelling site dominated by *Acropora* thickets, that were treated differently from other data. Figures in bold indicate significant results.

	Hard Corals		Acroporids		Pocilloporids		Faviids		Poritids		Soft Corals		Damage		Height	
Pontoon	**F**	?	**F**	?	**F**	?	**F**	?	**F**	?	**F**	?	**F**	?	**F**	?
Agincourt 4[a]	0.56	0.60	0.23	0.80	0.76	0.51	3.53	0.11	0.27	0.77	1.26	0.35				
Hardy[b]	0.93	0.51	0.16	0.76	1.51	0.44	0.06	0.85	0.62	0.58	0.92	0.51	**145.9**	**0.05**	3.42	0.21
Moore-GA[b]	0.08	0.93	0.05	0.95	0.78	0.56	2.76	0.27	1.38	0.42	0.03	0.97	2.13	0.32	0.24	0.81
Mor-GA[b] **(Ac)**	0.82	0.55	0.71	0.56	0.58	0.63	2.33	0.3	3.6	0.22	1.95	0.34	5.5	0.15	0.08	0.93

[a] 2,6 df; [b] 2,2 df

Table 4.8 Summary of the effects of snorkelling activities on corals. Data were mean annual changes in percent coverage at impact (**I**) and Control (**C**) sites for indicated taxa, or mean levels of damage or change in height of corals (right most columns). Where more than one control site was monitored, data were averaged across control sites. The **(Ac)** for the Moore-GA pontoon indicates data from a snorkelling site dominated by Acropora thickets, that were treated differently from other data.

	Hard Corals		Acroporids		Pocilloporids		Faviids		Poritids		Soft Corals		Damage		Height	
Pontoon	**I**	**C**	**I**	**C**	**I**	**C**	**I**	**C**	**I**	**C**	**I**	**C**	**I**	**C**	**I**	**C**
Agincourt 4	-1.22	1.08	-2.60	-0.87	-0.26	-0.39	0.32	0.11	0.02	0.31	0.45	-0.06				
Arlington	-1.34	.98	0.73	1.41	-0.07	0.38	-0.71	-0.14			6.37	7.98				
Hardy	5.47	2.65	0.97	3.98	-0.08	0.32	0.73	0.59	-0.25	0.12	1.63	0.48	1.6	0.22	-1.2	1.0
Moore-GA	13.28	11.92	12.43	10.98	0.46	0.47	0.33	-0.17	-0.29	0.24	0.35	1.03	0.09	-0.44	8.6	6.0
Mor-GA (Ac)	8.02	7.67	7.41	8.97	0.31	0.22	0.16	0.05	0.19	-0.26	0.20	1.19	-0.68	-0.08	-4.64	-4.88
Moore-SL	14.32	10.54	10.24	10.09	4.11	1.88	-0.24	-0.83			1.93	3.17				
Norman	3.11	0.27	1.87	0.25	0.21	0.07	0.82	-0.07	0.25	0.09	0.25	0.48	0.75	0.77	-0.25	-0.65
MEAN	5.95	3.50	4.44	4.32	0.67	0.21	0.20	0.03	-0.02	0.14	1.60	1.29	0.44	0.02	0.66	0.51

Table 4.9 Comparisons of mean change in coral cover, levels of damage and colony heights at all impact locations with mean change at all control locations. Means were compared by t-tests (t, df, ?$_t$), after first testing for homogeneity of variance (F, ?$_h$). Degrees of freedom for the t-tests were adjusted where ?$_h$<0.05. Figures in bold indicate significant results.

	Impact			Control			Variances		t-tests		
Variable	**Mean**	n_i	SE_i	**Mean**	n_c	SE_c	**F**	?$_h$	**t**	**df**	?$_t$
Hard coral	5.95	7	2.4	3.50	13	1.69	1.09	0.42	0.85	18	0.41
Acroporids	4.44	7	2.12	4.32	13	1.43	1.17	0.38	0.05	18	0.96
Pocilloporids	0.67	7	0.58	0.21	13	0.20	**4.75**	**0.01**	0.74	7.4	0.48
Faviids	0.20	7	0.20	0.03	13	0.11	1.67	0.21	0.82	18	0.43
Poritids	-0.02	5	0.11	0.14	11	0.13	2.94	0.15	-0.75	14	0.46
Soft coral	1.60	7	0.84	1.29	13	0.62	1.02	0.52	0.29	18	0.77
Damage	0.44	4	0.48	0.02	7	0.19	3.73	0.08	0.96	9	0.36
Height	0.63	4	2.82	0.51	7	1.88	1.28	0.36	0.04	9	0.97

Note: Some Standard Errors appear greater than the respective means because the data from which both were calculated were signed, and hence not bounded by zero.

Table 4.10 Summary of results of consultants' original statistical tests for the impact of resort diving on cover of corals, levels of damage and colony height (Site*Time terms only shown). The **(Ac)** for the Moore-GA pontoon indicates data from a diving site dominated by *Acropora* thickets, that were treated differently from other data. Figures in bold indicate significant results.

	Hard Corals		Acroporids		Pocilloporids		Faviids		Poritids		Soft Corals		Damage		Height	
Pontoon	**F**	?	**F**	?	**F**	?	**F**	?	**F**	?	**F**	?	**F**	?	**F**	?
Hardy[a]	0.95	0.44	1.35	0.27	1.15	0.34	0.54	0.70	0.60	0.67	1.15	0.34	**6.17**	**0.001**	1.61	0.21
Moore-GA[b]	0.46	0.74	1.03	0.40	0.51	0.66	2.07	0.16	1.97	0.16	1.26	0.32	0.06	0.98	3.00	0.07
Mor-GA[b] **(Ac)**	0.68	0.58	0.50	0.68	1.67	0.20	0.97	0.16	0.25	0.86	1.03	0.41	1.48	0.26	3.28	0.06
Norman[c]	**27.63**	**0.001**	**23.76**	**0.001**	2.16	0.18	0.008	0.93	5.40	0.05	1.15	0.31	1.31	0.29	**6.92**	**0.03**

[a] 4,54 df; [b] 4,24 df; [c] 1,8 df

Table 4.11 Summary results of re-analyses testing for the impact of resort diving on cover of corals, levels of damage and colony height (Impact*Time terms only shown, for full details see Appendix 1). The **(Ac)** for the Moore-GA pontoon indicates data from a diving site dominated by *Acropora* thickets, that were treated differently from other data. Figures in bold indicate significant results.

	Hard Corals		Acroporids		Pocilloporids		Faviids		Poritids		Soft Corals		Damage		Height	
Pontoon	**F**	?	**F**	?	**F**	?	**F**	?	**F**	?	**F**	?	**F**	?	**F**	?
Hardy[a]	6.34	0.24	0.38	0.65	1.36	0.45	0.36	0.66	3.24	0.32	0.59	0.58	13.35	0.17	0.35	0.61
Moore-GA[b]	0.34	0.75	0.02	0.98	0.05	0.95	2.27	0.31	1.33	0.43	6.33	0.14	**57.19**	**0.02**	**82.03**	**0.01**
Mor-GA[b] **(Ac)**	10.61	0.09	0.05	0.95	1.24	0.45	0.95	0.51	.37	0.73	1.81	0.36	3.28	0.23	0.05	0.95

[a] 2,2 df; [b] 2,2 df

Table 4.12 Summary of the effects of diving activities on corals at pontoons. Data were mean annual changes in percent coverage at impact (**I**) and Control (**C**) sites for indicated taxa, or mean levels of damage or change in height of corals (right most columns). Where more than one control site was monitored, data were averaged across control sites. The **(Ac)** for the Moore-GA pontoon indicates data from a diving site dominated by Acropora thickets, that were treated differently from other data.

	Hard Corals		**Acroporids**		**Pocilloporids**		**Faviids**		**Poritids**		**Soft Corals**		**Damage**		**Height**	
Pontoon	**I**	**C**	**I**	**C**	**I**	**C**	**I**	**C**	**I**	**C**	**I**	**C**	**I**	**C**	**I**	**C**
Hardy	2.82	2.09	0.31	1.12	0.21	0.44	0.43	0.52	0.38	0.49	2.10	1.10	1.90	0.30	-3.04	-1.48
Moore-GA	7.09	7.15	5.71	6.86	0.04	0.27	0.05	-0.19	2.06	-0.36	0.35	0.80	-0.10	0.15	2.88	1.68
Mor-GA (Ac)	6.26	8.53	5.05	6.75	-0.01	0.32	0.15	0.02	-0.04	0.01	0.96	1.50	-0.75	-0.02	-7.76	-1.2
Norman	-3.03	5.20	-0.80	4.10	-0.54	-0.08	0.08	-0.26	-1.02	-1.14	0.38	-0.40	1.98	0.43	0.92	3.69
MEAN	3.29	5.82	2.57	4.95	-0.08	0.28	0.18	0.06	0.35	-0.12	0.95	1.05	0.76	0.18	-1.75	0.24

Table 4.13 T-tests comparing mean change in coverage at all resort diving impact locations (mean impact) with mean change at all control locations (mean control). Tests for homogeneity of variance were done (F, ? $_h$) and degrees of freedom were adjusted where necessary. Figures in bold indicate significant results.

	Impact			**Control**			**Variances**		**t-tests**		
Variable	**Mean**	**n_i**	**SE_i**	**Mean**	**n_c**	**SE_c**	**F**	**? $_h$**	**t**	**df**	**? $_t$**
Hard coral	3.29	4	2.30	5.82	7	1.14	2.31	0.18	-1.11	9	0.29
Acroporids	2.57	4	1.65	4.95	7	1.12	1.24	0.37	-1.24	9	0.25
Pocilloporids	-0.08	4	0.16	0.28	7	0.11	1.17	0.40	-1.85	9	0.10
Faviids	0.18	4	0.09	0.06	7	0.15	5.34	0.10	0.54	9	0.60
Poritids	0.35	4	0.64	-0.12	7	0.24	3.97	0.07	0.82	9	0.43
Soft coral	0.95	4	0.41	1.05	7	0.38	1.53	0.39	-0.18	9	0.86
Damage	0.76	4	0.70	0.18	7	0.11	**24.22**	**0.001**	0.82	3.1	0.47
Height	-1.75	4	2.35	0.24	7	0.95	3.54	0.09	-0.94	9	0.37

Note: Some Standard Errors appear greater than the respective means. This arises because the data from which both were calculated were signed, and hence not bounded by zero.

4.2.3 Impacts of Divers

Original analyses of the effects of divers at three pontoons identified potential impacts at two: Hardy and Norman reefs (Table 4.10). At Norman reef there was only one control site, so the test of impact was confounded with natural spatial variation. Re-analysis of data from Hardy reef did not identify any significant impacts (Table 4.11). There were no changes in the levels of damage to corals on the dive trail at Moore-GA pontoon detected in the consultant's analyses (Table 4.10), probably because monitoring was begun to assess the impacts of replacing the pontoon, and the dive trail had been in use already for three years. There were, however, significant differences in levels of damage at control and impact sites when averaged over times ($F_{2,12} = 36.03$, $p < 0.001$). Re-analysis did show up significant changes in levels of damage and heights of corals along the dive trail compared with control sites at Moore-GA pontoon (Table 4.11; see appendix 3).

Trends in mean coral cover, levels of damage, and heights of corals showed that resort diving may have impacted on cover of Acroporids and Pocilloporids, levels of damage to coral, and height. Total coral cover increased 25% more at the dive site at Hardy reef than at control sites, but at the other pontoons where the effects of divers were monitored, corals either decreased in cover or increased less at the dive site than at control sites (Table 4.12). The rate of increase in cover of Acroporids at dive sites was on average only 52% of that at control sites across all studies, and cover of Pocilloporids decreased slightly at dive sites compared with increases at control sites (Table 4.12). Faviids, Poritids, and Soft Corals, however, on average grew similarly or better at dive sites than at control sites (Table 4.12). It may be that suppression of cover of Acroporids and Pocilloporids allowed increases in slower growing corals. Changes in levels of damage were three times greater at dive sites than at control sites except at Moore-GA pontoon (Table 4.12), where the dive trail had been in use for three years before monitoring started and levels of damage were declining. On average, heights of corals decreased by 1.75 cm per year at dive sites and increased by 0.24 cm per year at control sites (Table 4.12). In *Acropora* thickets at Moore Reef, black band disease affected the heights of coral at one control and the dive trail, causing reductions in average height of live colonies (Ayling & Ayling 1994b). The decrease in height was greater at the dive site (9.7 cm over 15 months) than at the affected control (2.9 cm over 15 months). None of the differences in these responses of corals between control and impact sites were statistically significant (Table 4.13), though again our tests were weak. Nevertheless, consistent trends in means suggested that some corals along dive trails may have suffered increased levels of damage, decreases in size and perhaps decreases in growth compared to corals at non-dive control sites. These are candidate effects for future monitoring studies.

4.3 Fish Aggregations

4.3.1 Size and Composition

The methods of counting fish aggregations differed widely among pontoons (Table 3.10), and it was not possible analytically to compare the observed aggregations. Total counts of fish under pontoons were available from all studies except the Kelso baseline study, but some included site-attached fish as well as fish in aggregations. Total numbers of fish in aggregations ranged from 53 at Arlington pontoon to an estimated 2430 at Norman pontoon (Table 4.14). The numbers of large predatory fish (Carangids, Lethrinids, Lutjanids and Serranids) ranged from 0 to 304 (Table 4.14). The composition of the predatory assemblages varied among pontoons, with 88% of the predatory fish at Hardy pontoon made up of Carangids, compared with 93% Lutjanids at Norman reef. The aggregation at Wistari was unusual in that 31% of the aggregation was Serranids, which were found only in small numbers elsewhere. In the absence of fish feeding at Moore-GA pontoon, an aggregation consisting of goatfish, drummers and fusiliers was resident under the pontoon. Thus, both abundance and composition of aggregations varied greatly among pontoons.

Table 4.14 Size and composition of fish aggregations at eight pontoons. Numbers are approximate.

Species/Family	Agin2d	Agin3a	Agin4	Arling	Hardy (old)	Hardy (new)	Mor-GA (old)	Mor-GA (new)	Mor-SL	Norm[n]	Wistari
Acanthurids	-	34	8	-	-	-	-	-	-	45	-
Caesionids	126	-	155	20	800	400	70	110	100	2000	-
Carangids	4	0	0	0	147	9	0	0	0	14	50
Cheilinus undulatus	4	-	-	-	3	2	-	-	-	6	-
Echeneis naucrates	-	-	-	-	-	-	-	-	-	-	15
Lethrinids	18	15	8	20	0	0	0	0	10	4	51
Lutjanids	2	19	2	8	20	37	0	0	6	282	0
Serranids	5	-	1	-	-	-	-	-	-	4	46
Kyphosids	39	4	-	5	-	28	5	30	5	75	-
Mullids	300	-	-	-	-	-	100	250	-	-	15
Siganids	51	2	2	-	-	-	-	-	-	-	50
Total fish	1700	75	180	55	975	490	175	390	120	2430	230
Total predators	35	35	10	30	170	50	0	0	15	310	150

Temporal fluctuations in abundances of some families of fish varied between pontoon and control locations. In general, the families affected were, not surprisingly, those families most commonly found in pontoon aggregations: Lethrinids, Lutjanids, Caesionids, Carangids and Kyphosids. At Arlington and Moore-SL pontoons, mean densities of fish were similar at pontoon and control sites except for densities of Lethrinids at Arlington pontoon, which were up to 20 times more abundant at the pontoon than at control sites.

4.3.2 Factors Influencing the Sizes and Compositions of Aggregations

Several factors may have influenced the sizes and compositions of aggregations of fish at pontoons, including the size of the pontoon, the nature of fish feeding, and spatial variation in abundance and composition of assemblages of fish on different reefs. An increase in size of the pontoon at Moore-GA and Norman pontoons resulted in increases in the sizes of the fish aggregations. At Moore reef, the Moore-GA pontoon increased in area by a factor of 2.2, and so did the total size of the aggregation. At Norman reef, the size of the pontoon increased by a factor of 1.2 and the total size of the aggregation increased by 2.7 times. This was due to a dramatic increase in the number of Caesionids. The size of the pontoon apparently had considerable influence on the sizes of the aggregations, but based on the correlative evidence from only two pontoons, and no information about other changes in the operations that may have coincided with increased pontoon size, no definite conclusions can be drawn about the mechanisms for such effects.

The composition of fish assemblages appeared to be strongly related to the extent and type of feeding that occurred at pontoons. At Hardy Reef, where a pontoon was moved from one site to another, the fish aggregation associated with the pontoon at the old site moved to the new site (Ayling & Ayling 1994a), but the size of the aggregation decreased after fish feeding was discontinued. The abundance of trevally decreased from approximately 150 to 9 over a period of 6 months. At Moore-GA, where there was never any fish feeding, there was no aggregation of predatory fish. Fish feeding at Low Isles pontoon was discontinued for 3 weeks in 1990 because of aggressive behaviour by trevally toward tourists, and numbers declined from 15 to 1-2 after 4 days (Marine Environmental Monitoring 1994). After fish feeding recommenced, numbers of trevally increased rapidly to 15 again. At Moore-SL pontoon, staff divers fed fish by hand in front of an underwater observation chamber but few predatory fish aggregated around the pontoon. These anecdotal observations indicate that the amount of food offered during fish feeding also played an important role in determining the sizes of the aggregations. Sweatman (1996) also found that fish feeding was an important factor in aggregating fish around pontoons.

After removal of pontoons at Wistari, Hardy, and Agincourt 3a reefs, fish aggregations rapidly dispersed. Monitoring of the old pontoon site when the Hardy pontoon was removed showed that by 9 months after the removal, fish assemblages at the pontoon site were similar to those at control locations (Ayling & Ayling 1994a). When the Wistari pontoon was moved to its cyclone mooring, remora and batfish continued to live under the pontoon, but fish at the original site returned to pre-installation numbers and composition (Fisheries Research Consultants 1992). Similarly, numbers of predators at Agincourt 3a pontoon site decreased over time, and 10 months after the pontoon's removal were similar to those at control sites (Gibson *et al.* 1994). Clearly the influence of the pontoon on fish aggregations was short-lived once the pontoon was removed.

4.3.3 Effects of Pontoon Aggregations on Abundances of Fish Near the Pontoon and Elsewhere

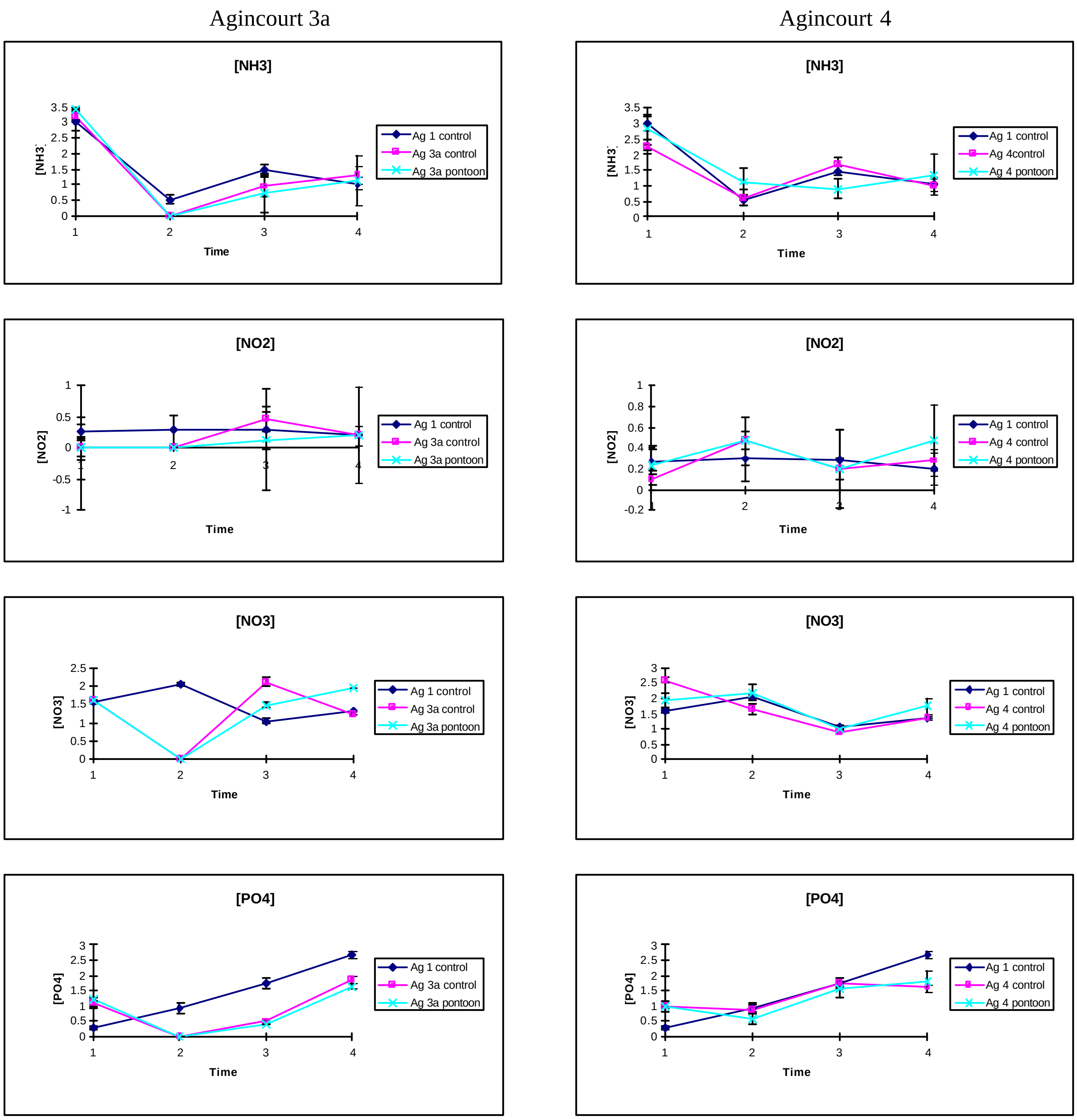
It was claimed that the Wistari pontoon had a significant 'depletion effect' on other areas of the reef, with decreases in abundance of fish over 11 months at control sites 400 and 1800 metres from the pontoon (Fisheries Research Consultants 1992). On re-analysis, there was little evidence that increases at the pontoon site were accompanied by decreases at control sites, however (Sweatman 1996). Monitoring of fish at five pontoons (Arlington, Hardy, Moore-GA, Moore-SL and Norman reefs) was specifically aimed at detecting depletion at controls in response to the pontoon. None found any evidence of declines in abundance of fish at control sites.

It was evident in some of the file material for the programmes we reviewed that there was some concern by the GBRMPA that the large number of predatory fish aggregated at pontoons might have affected local populations of small fish. At Hardy pontoon, a study purporting to test this hypothesis found that the abundance of site-attached Pomacentrids and small Labrids increased at the pontoon site and at two control sites. Chaetodontids declined under pontoons at Agincourt 2d, Agincourt 3a, and Norman reefs where coral cover also declined significantly, while at Hardy and Moore-GA pontoons, there were no detectable changes in the abundance of Chaetodontids at the pontoon site. Chaetodontids are not prey species of the major predators found in aggregations at pontoons. We found no evidence in the reports we reviewed that aggregations of large predatory fishes at pontoons affected local abundances of prey species.

4.4 Water Quality

We saw no evidence that pontoons affected water quality, based on the very limited information available. Data from water quality surveys at Moore-SL and Agincourt 2d reefs are not useful for assessing whether the presence of pontoons affected levels of nutrients in the water (see section 3.3). Data from Agincourt 1, 3a and 4 reefs suggested that the different reefs had different water quality, but the quality of water within one reef was similar at pontoon and control sites (Figure 4.1). For all four parameters measured in this study, trajectories at control and pontoon sites at Agincourt 3a and 4 reefs were similar, while the Agincourt 1 control differed from both. There were no temporal variations consistent with an impact of installation or removal of a pontoon on water quality since control sites behaved similarly to the pontoon site at each reef. These data are not sufficient to claim categorically that there are no impacts of pontoons on water quality, partly because of their high variability (Figure 4.1) and partly because of the limited geographic and temporal scope of the data, coming from only one outer-reef complex.

Figure 4.1 Means and SE of water quality variables at Agincourt Reefs. Pontoon relocated between times 2 and 3



V ADMINISTRATIVE PROCEDURES AND PROJECT MANAGEMENT

5.1 Administrative Structure and Funding of Pontoon Monitoring

The GBRMPA now usually requires pontoon operators to fund the impact monitoring associated with the installation, operation, removal, or re-location of each pontoon. There are four key parties in the monitoring programmes funded by developers: the Proponent, the Consultant, and two sections of the Authority: the Impact Assessment Unit (IAU) in the Environmental Impact Management Section, and the Monitoring Unit in the Research & Monitoring Section (R&M). Initially the Proponent contacts the Authority about his/her wish to install a pontoon, and the request is passed to the IAU for assessment of potential impacts and initiation of permit procedures. During the process of permit assessment by the IAU, personnel from GBRMPA Research and Monitoring Section, the Queensland Department of Environment and Heritage (QDEH), the proponent, naval architects, and other interested parties may visit the site of the proposed pontoon to get initial impressions about the suitability of the site(s) for a pontoon installation, and about whether monitoring is required and what form it should take.

Once personnel from the IAU and R&M have decided what impacts require monitoring, the Project Officer in R&M writes to the Proponent to solicit the choice of a consultant, outlining briefly the monitoring programme required. Once the Proponent has nominated a consultant acceptable to the Authority, Minimum Monitoring Requirements are sent to the Consultant who then submits a proposal. The Authority enters into a Consultancy Contract with the Consultant and the monitoring programme is managed wholly by the Authority. The Proponent is sent all reports from monitoring.

Funding for pontoon monitoring is provided by the Proponent. The full cost of the monitoring programme is paid to the Authority before the programme starts. The Proponent also must deposit a bond with the Authority to cover unforseen damages, reparation in the event of accidents, and a number of other specified contingencies. The Authority also charges a management fee of 5% of the cost of the programme. Money is paid to the Consultant by the Authority in instalments negotiated individually by the Consultant and the Authority. Usually, the instalments are paid as an advance before field work starts, and progress payments on receipt of progress reports and the draft final report, with the remainder paid after the Authority accepts the final report.

5.2 Planning and Proposal Review

The consultant is strongly urged to do a pilot study or use relevant prior data to assess the number of replicates required in the proposed monitoring design. These data are in theory used to design the monitoring programme in conjunction with Minimum Monitoring Requirements specified by the Authority. The draft proposal is reviewed internally by GBRMPA staff, and sometimes QDEH staff, and sent out to independent scientists to review. In theory, the consultant may then be required to modify the proposed monitoring programme on the basis of the reviewers' comments.

In practise, pilot studies were done for only two pontoons, and most proposals contained no formal evaluation of sampling design, expected analyses, sample sizes, or statistical power. We found that some proposals were never reviewed externally, and reviews of several were not completed before monitoring started. Two pontoons were monitored without the final proposals having been accepted. Potentially, this meant that flaws or omissions in the monitoring programme would go unchallenged until after all the field work had been done, ultimately leading to failure to achieve the aims of the programme. The time between acceptance of a final proposal and 'baseline' studies ranged from -3 months to +2 months. These features, which were more the rule than the exception in the planning of the studies we reviewed, illustrated why baseline studies were not temporally replicated in most cases: there was no time to do so.

5.3 Reporting, Review, and Responses to Reviewers

Progress reports were not submitted by some consultants, while others over-reported by submitting large volumes after each sampling event (4 reports over 12 months). Several consultants, however, consistently submitted brief, informative, one-page summaries of results no more than 2 months after sampling trips, demonstrating that the requirement for multiple progress reports was workable, though reporting deadlines for such brief reports should be within one month of the field surveys to allow early response to any 'drastic' impacts. The Authority has little leverage for earlier submission, however, apart from withholding payment when consultants fail to submit reports in the agreed time under the current operating procedures.

In the case of the Kelso reef pontoon, delays in reporting resulted in part of the 'baseline' survey being completed 17 months after installation of the pontoon, and no further monitoring of the impact of the pontoon. The initial survey was done in December 1990, just days before the pontoon was installed. Sub-consultants submitted a brief report on what they had done, but it was not until

January 1992 that the baseline report was submitted and the serious omissions in baseline data were noticed. By then the pontoon had already been operating for a year with no monitoring of impacts. Similar delays between the end of field work and submission of draft reports occurred for the Moore-SL and Arlington pontoons.

Reviewers consistently criticised aspects of monitoring programmes, both at proposal and when reported, for many of the same reasons as we do in this report. Specific suggestions on how to better monitor pontoons have been made since 1989. Unfortunately, many of the constructive comments by reviewers came too late to be incorporated in the existing, and in some cases new pontoon, monitoring designs. This in part arose because of the long periods between final field trips and the submission of draft final reports in some programmes. In response to many suggested changes, both consultants and proponents sometimes argued that 'academic reviewers' did not understand the 'real world' constraints of money and time involved in monitoring pontoon (and other) developments. It was argued that the designs that would have satisfied some reviewers would be too expensive as impact assessments for pontoon operations. This view found support from some Authority staff, despite sound 'compromise' advice from several Research and Monitoring section (R&M) staff (pers. obs.). Several different reviewers independently pointed out, however, that the designs as they stood were not sufficiently powerful to detect other than extremely large impacts, assuming that the data were properly analysed.

One of the main criticisms that was levelled at the procedures adopted by the Authority was the lack of a firm purpose behind monitoring. Reviewers clearly believed that the responsibility for defining specific aims for monitoring lay with the Authority:

> 'This process (power analysis) will require input from GBRMPA regarding what it feels are important levels of change which must be determined by the monitoring programme.' (1989);
> 'Responses of the tourist operator hinge on the definitions of the management trigger level.' The reviewer goes on to point out that there was no definition of what the management trigger was, nor what effect sizes were considered important (1991);
> 'The question of how to identify a damaging exposure (concentration and duration) to elevated levels of these nutrients also needs to be addressed by the Authority.' (1991);

> ‘Is the aim to quantify damage because some maximum amount of allowable damage has been fixed, and if exceeded, it would be recommended that the structures be removed or modified?’ (1992);
>
> ‘A larger issue which GBRMPA should consider...is to define the purpose of monitoring the impact of divers on the reef. If divers do cause coral breakages, [...], is GBRMPA likely to exclude divers from the area? Care must be taken to direct monitoring resources to issues where a management response is possible or probable.’ (1992);
>
> ‘More basic than these is the identification of the kinds and magnitudes of differences that would be considered significant by managers. These are not mentioned here and are presumably the domain of the Authority.’(1994).

While pontoons were relative novelties on the reef and their environmental impacts were not known, these criticisms could not be addressed. The Minimum Monitoring Requirements supplied by the Authority to the consultants since 1992 go some way to addressing some of the above issues. The recommendations in them, however, vary from case to case, and seem not to represent formal policy on monitoring. We found evidence on Authority files that formal procedures had been begun by R&M staff in 1991 and again in 1993 to address some of these issues in the interests of developing formal monitoring policy for pontoon (and other) activities in the Marine Park. To our knowledge, none has yet been completed. Failure of these initiatives possibly reflects disparate opinions within the Authority about the needs of monitoring and the absence of a process through which to resolve these views in the face of concern about the costs of monitoring from pontoon proponents.

Whilst the Minimum Monitoring Requirements advice was a ‘step in the right direction’, it too needs further development. For example, in the correspondence sent to consultants, it is suggested that designs should be able to detect an effect size of 0.2 with a power of 0.8. It was not clearly specified, however, what was meant by an effect size of 0.2, or at what critical Type I error rate the power should be 0.8. Effect size could be formulated in several different ways, and without specifying what the 0.2 represented (exactly), the statement had little meaning. Further, there was no apparent *a priori* reason for choosing that effect size. The type of effect size and the model that gave rise to the value was not specified anywhere. The same effect size was apparently recommended for all aspects of monitoring at pontoons, in all types of assemblages (fish and benthic), with no regard to the different consequences of a change of that magnitude in those different assemblages. For example a decline in coral cover corresponding to an effect size of 0.2 may be of more concern in a coral community with very low coral cover than in a diverse community with very high coral cover. The stipulation of important effect sizes that should be the target of monitoring design is often difficult, and it was inappropriate to simply recommend a blanket value for all occasions (Mapstone 1995, Oliver 1995).

Baseline studies were criticised as inadequate because there were few studies that included details of pre-impact temporal variation in variables. In 1989, two reviewers of proposals for pontoon monitoring recommended that more than one sample be taken before the impact occurred, and since then the lack of adequate baseline data has been remarked on by reviewers of four other pontoon monitoring projects. The Authority's stance appeared to be that 2 samples before installation was adequate to document the ‘existing state of the environment and any trends towards increasing or decreasing abundance of organisms.’ In the case of organisms that respond to daily, lunar or seasonal cycles, the timing of baseline studies would have had a very large influence on the interpretation of subsequent monitoring, and two such observations were almost certainly insufficient for the stated objectives.

Similarly, one reviewer and a consultant biostatistician commented on the time scale of monitoring compared with the scale of natural temporal variation in target species. Some studies on fish assemblages were designed to include some estimate of ‘seasonal’ (ie repeat measurements a month apart) variation in abundance, but monitoring requirements for benthic assemblages usually stipulated sampling times ‘just prior to installation’, occasionally another immediately after installation, and again 6 and 12 months after installation. How these times related to the expected impact of the pontoon was not clear.

Reviewers repeatedly called for more control sites. Some reviewers stated explicitly why more control sites were required, explaining in detail the statistical models of monitoring designs. For example:

> ‘Sampling at only two control sites is almost certainly insufficient to provide reasonable power for tests of a pontoon effect. Variation among control sites will be the error term against which the presence of any anomalies (= impacts) at the pontoon site will be measured. Hence, the more control sites that can be

> sampled, the lower the risks of incorrectly either concluding that an impact has occurred or failing to detect a real effect of the pontoon.' (1989)
>
> '...main point of control sites [...] (is) to avoid spatial confounding and provide an appropriate estimate of 'natural' variation against which an impact can be assessed.' (1990)

Similarly, in February 1991, a reviewer pointed out that several control sites were required because of the need to contrast the impact site with controls in combination. In June 1993 a reviewer went into great detail about the appropriate design and statistical analysis of impact assessment. Unfortunately by then most of the pontoon studies were over. These comments should be incorporated into any future monitoring programme.

In response to these calls for more control sites, the Authority (January 1992) agreed that additional controls would always be beneficial, but that 'we must be realistic about costs and logistics'. Whilst the Authority apparently was interested only in the minimum number of replicates and controls necessary to distinguish an impact (of unspecified size), reviewers were saying repeatedly that the small number of controls in several programmes was inadequate, and that the minimum number needed to be greater than two.

Levels of replication were largely inadequate to detect impacts according to some reviewers. Based on Mundy's (1991) work, eight replicate line transects was the minimum recommended to detect a relative change in coral cover of 20% against a critical significance criterion of 0.05. Inadequate replication was mentioned by reviewers in 1989 (3 sections), 1990 (one case), 1992 (one case) and 1993 (one case). Some of these comments came too late to be incorporated into designs for other pontoon monitoring programmes. However, early comments that eight transects were the minimum for coral surveys, and 3 replicates were inadequate for fish surveys could have been incorporated into subsequent designs. It should be noted here, though, that several of the reviewers confused the advantage of increased numbers of control sites and increased replication of sampling units within sites. Increasing the numbers of control sites would have improved the power of the key tests of impacts far more efficiently than increasing replication within sites (Keough & Mapstone 1995). In designs of the type used in monitoring impacts of pontoons, the main use of sample unit replication is as sub-samples with which to adequately characterise the variables of interest at each site, not as independent estimates of impact or control status.

Monitoring of fish aggregations has been plagued by difficulties with replication and independence of observations. Several reviewers pointed out that using fish counts on consecutive days as replicates did not in fact constitute appropriate replication for spatial comparisons. Reviewers also emphasised that these 'replicates' were highly likely to be non-independent, therefore violating a major assumption of the analyses used. The earliest of these warnings of non-independence and inappropriateness came in April 1992, in time to be incorporated into subsequent sampling at several pontoons, but they were not heeded. Reviewers of draft reports for several pontoons also complained of non-independence of 'replicate' fish counts, but the treatment (and analyses) of the 'replicates' changed little in final revisions of the reports.

Several reviewers commented on the appropriateness of variables monitored. One reviewer pointed out that classification of fish to family level was likely to obscure real differences attributable to the pontoon because each family contained some species which were sensitive to habitat degradation (or increased levels of damage) and others which were not. Many calls were made for corals to be classified to life-form within major genera, but this was usually not done.

In summary, most of the major criticisms levelled at pontoon monitoring programmes in this review had already been pointed out repeatedly by reviewers of proposals and reports. There was little documented evidence that information from, or criticism of, monitoring programmes had been transferred among programmes.

VI DISCUSSION & RECOMMENDATIONS

6.1 Monitoring Design and Implementation

Some aspects of the design and/or analysis of all the monitoring programmes we reviewed have been criticised for failures of varying degrees of severity, both by us and by previous reviewers. The main problems included lack of definition of aims, confounding of sources of impact (the pontoons) with various un-related effects, non-independence of data, inadequate or lacking baseline information, and inappropriate analytical models.

The aims of all monitoring programmes were poorly defined. With one exception, no report presented any quantitative description of what constituted an 'impact'. In that case, acceptable impact at the pontoon site was defined as 'not more than 20% (relative) [change] greater than at unused 'control' sites'. There was no definition of the direction of change expected.

In an impact assessment, defining the magnitude and direction of unacceptable change *a priori* allows for unambiguous management decisions and powerful designs for monitoring programmes. While little was known about the potential impacts of pontoons, lack of specific quantitative aims was perhaps excusable, but monitoring programmes should in that case have been seen as investigative pattern-seeking exercises, rather than hypothesis-testing exercises. The lack of specific objectives to which monitoring was being designed may account for the generally low-power designs used in most studies. Now that over 10 years have passed since the first pontoons were installed, it is time to set specific ecological criteria for assessments of impacts of pontoons.

Given the generally non-specific nature of the objectives for most studies, it might be argued that designs were generally adequate for those broad aims. However, monitoring programmes suffered from both spatial and temporal confounding, alterations in basic designs between repeat samplings, and generally low replication of control sites and (in some cases) sampling units. Spatial confounding occurred when only one control site was compared with one impact site. In these cases, there was no way of separating any effect(s) of the pontoon from natural spatial variation among sites. The only way to avoid that spatial confounding was to increase the number of control sites (Hurlbert 1984, Andrew & Mapstone 1987, Underwood 1981, 1991, 1992, 1993, 1994, but see Stewart Oaten *et al* 1986, Stewart Oaten 1996a,b). For most of the benthic monitoring of pontoons, two control sites were sampled. While two controls were clearly better than one, that level of replication of sites was still inadequate, resulting in very low likelihood of detecting real impacts if they occurred. These issues were not new, and there was considerable literature available which, had it been considered, would have given ample warning of the most of the inadequacies we found (*e.g.*, Andrew & Mapstone 1987, Elliott 1977, Green 1979, Hurlbert 1984, Underwood 1981). The issues were also raised repeatedly by external reviewers.

Temporal confounding occurred in a number of instances, when changes in the design of monitoring programmes coincided with installation of the pontoon. This happened at two pontoons, where changes in number and size of replicates occurred between the baseline and first post-installation surveys. Because of the coincidence of changes in design and installation of the pontoon, it was not possible to know unambiguously whether differences before and after installation were due to the pontoon or to the change in method. The solution to this problem was to ensure that the design and methods were adequate before starting the monitoring programme, and replicate sampling times before the pontoons were installed. This would require far earlier notice of the intention to install a pontoon than was the case in any of the studies we reviewed.

Inadequate baseline sampling was common to all monitoring programmes. Baseline studies should provide estimates of temporal variability at all sites before an impact occurs (Keough & Mapstone 1995, Stewart-Oaten *et al* 1986, Green 1989, Underwood 1991). Benthic and fish assemblages are not static over time, so cannot be characterised by a single survey. For instance, turnover of individual corals on coral reefs can be up to 60% of the initial population in the space of three years (Nelson 1994). In the face of such turnover, the potential for dramatic changes in abundance and composition is great. One survey of benthic assemblages before a putative impact does not provide an adequate basis for deciding that temporal variation at an impact site differs from what might have occurred in the absence of an impact. The situation is worse for highly mobile fishes.

In theory the temporal scale of sampling before the potential impact should be similar to the temporal scale of sampling after the impact (Keough & Mapstone 1995, Stewart-Oaten *et al* 1986, Underwood 1991). In practical terms this is not possible for pontoon installations under current guidelines because post-installation sampling is often open-ended. Nevertheless, the need for some temporal sampling on a scale appropriate to the variables being measured has been emphasised for some time, but did not occur in these studies. The monitoring programmes reviewed here provided no rationale for the timing of sampling events which, in the majority of cases, were spaced evenly 6 months apart following the pontoon installations. Abundances of fish vary at many time scales (Williams 1991, Richards 1992), and sampling at time scales larger than the scale of variation may misrepresent the differences (or similarities) between abundances before and after the pontoon was installed (De'Ath 1994, Underwood 1991). Underwood (1991) recommended sampling at random intervals before and after potential impacts to remove the possibility of missing important components of temporal variation. Whilst it might be argued that some of these issues were relatively un-explored in the impact assessment field 10 years ago, they were clearly discussed 5 years ago, and perhaps should have been taken into account in the design of more recent monitoring studies.

Investigation of the distance(s) over which pontoons affected abundances of mobile fish (the 'depletion effect') and the effects aggregations had on local sedentary fishes also were flawed. The underlying assumption of these studies was that the pontoon acted as an aggregating device causing greatest declines in abundance of fish at locations closest to the pontoon. Non-pontoon sites were spaced at varying distances away from the pontoon but were small and few. It was unlikely that (at most) three small sites in the expanse of a reef would provide useful information about movements of fish to a pontoon, especially since in none of the studies were fish individually recognisable (*e.g.*, by tagging). It seems unlikely, therefore, that the monitoring programmes we reviewed would be sensitive indicators of any 'depletion' effects.

The effects of pontoons on abundances of relatively sedentary fishes were typically measured by comparing transect counts of site-attached fish at the pontoon with counts at control sites. For this purpose, the methods - if not the design - were appropriate. In several instances, however, the reason for these comparisons was apparently to assess the effects of aggregations of large predatory fishes at pontoon sites on the sedentary fishes. The causal link between the aggregations and patterns in abundances of other fishes cannot be made on the basis of the monitoring done, however. Differences in abundances of the sedentary fishes might also have been related to changes in coral cover as a result of the pontoon, disturbance by humans, changes in light regime, changes in water quality, or other correlates of the pontoon installation. None of the monitoring programmes provided the basis for discriminating between these factors and the effect(s) of aggregations of piscivores.

The level of taxonomic resolution varied enormously among studies, particularly for benthic taxa. The only benthic variables that were included in all pontoon studies were the total percent coverage of hard corals and the total percent coverage of soft corals. Most studies also included estimates of the percent coverage by major taxonomic groupings such as Acroporids, Pocilloporids, Faviids and

Poritids, and some provided percent cover estimates for genera or species of hard and soft corals. One problem with resolving taxa only to family-level is that real impacts may be smothered by lumping together species that do respond to the pontoon and those that do not. For example, the damage snorkellers and divers have on benthic assemblages will depend greatly on the species composition of the assemblages (Hawkins & Roberts 1992, Rouphael & Inglis 1995). Thus, one might expect that a greater impact would occur at pontoons with high coverage of branching Acroporids or delicate foliose *Montipora* and *Pavona* than at pontoons with mostly robust digitate Acroporids or massive corals. If robust species (for example encrusting *Montipora*) cover more area than delicate species (*e.g.*, small, delicate *Acropora nana*), then an analysis done on Acroporids as a family is unlikely to detect loss of cover of the delicate species. Similarly, shifts in the structure of assemblages are likely to be missed at broad levels of taxonomic resolution. It is extremely unlikely that the installation of a pontoon would cause a shift from dominance of a coral assemblage by Acroporids, but the actual species or morphological composition of acroporids in the assemblage could change through loss of susceptible species or failure of recruitment by some species. The same comments could apply to the taxonomic resolution in fish studies, with some species in each family responding to the pontoon while others may not.

Finally, the choice of variable(s) to monitor in some of the work we reviewed was almost certainly inappropriate. For example, estimates of percent coverage by corals are likely to be only coarse indicators of gross impacts, and will be poor measures of population and community dynamics. Changes in coral cover may not be an appropriate measure of impact for many aspects of pontoon associated activities. Ayling & Ayling (1994a,b,c) have shown at several pontoons that although damage is greater at snorkel sites than at control sites, the damage does not translate into changes in coral cover. Although there was little impact of pontoons and their associated activities on coral cover, this lack of effect on cover did not necessarily mean that pontoons were not harmful to coral assemblages. In the earlier stages of using pontoons on the GBR a coarse measure of their impacts may have been legitimate, and did indicate some gross impacts of, for example, damage by mooring systems. With increasing knowledge of the activities that occurred at pontoons, and their likely specific impacts, it might have been expected that the variables being monitored would be changed to provide more specific measures of hypothesised impacts. In many cases, this seems not to have happened. For example, in the case of pontoon footprints, counts of individuals (to estimate mortality rates), and estimates of bleaching or damage might have better reflected the potential impacts associated with shading or abrasion by anchor chains than simple estimates of percent cover. File records demonstrate that the Authority has, on a number of occasions, identified lists of specific measures of impact, but many of these seem to have been disregarded in the formulation of monitoring programmes, without documentation of the reasons for doing so.

Exceptions to these statements occurred with respect to monitoring the effects of snorkellers and divers. Variables were chosen more specifically for monitoring the effects of snorkellers at several pontoons, particularly in recent years. Snorkellers were likely to kick corals or stand on them, causing damage to polyps, broken branches, or fragmentation, but these impacts may not have affected percent cover unless damage was extreme. Estimates of damage, rates of fragmentation, damage to polyps on the tops of *Porites* colonies frequently used as rest areas, or partial mortality are more likely to reflect the effects of snorkellers on benthic communities than measures of percent coverage. Studies at various pontoons estimated levels of damage, either to marked individuals or along transects, as measures of the direct effects of snorkellers on corals. Such activity-specific measures should be employed in all future pontoon monitoring programmes.

6.2 Impacts of Pontoons on Benthic Assemblages

The studies we reviewed suggested that pontoons and associated activities have had small detrimental effects on coral assemblages in the vicinity of the pontoons. Some corals under the pontoon footprint bleached and died following pontoon installation (or removal), but net changes in coral cover were usually small (2-3% per annum). The major changes associated with pontoon structures apparently resulted from poor anchoring technology which resulted in widespread damage and mortality of corals through the movements of anchor chains.

Such problems are unlikely to recur because pontoon mooring systems are now required to pass strict assessment and have been refined to avoid such damage. Current GBRMPA guidelines require pontoons to be positioned over sand as much as possible so that shading of corals is avoided. Any corals that are small enough to move are translocated away from mooring lines and the footprint. These changes in guidelines mean that the impacts that occurred in the past as a result of moorings and the pontoon footprint are unlikely to occur at future pontoon installations. We found no reports of monitoring the effects of pontoons on soft-sediment assemblages, apart from a research project by Cohen (1990). Cohen's (1990) work was not formally part of monitoring studies, and this is perhaps worth investigation in the future, even though any impacts on fauna under pontoons moored over sand are likely to be inconspicuous to casual observers.

Snorkelling had little measurable detrimental effect on coral cover, but the activities of resort divers appeared to depress growth of corals at dive sites relative to controls. Snorkelling and diving activities were regularly associated with increased levels of damage to corals. A number of factors may have influenced the amount of damage caused by divers and snorkellers. Ayling & Ayling (1994b) considered the topography of the snorkel or dive site was a major factor affecting the degree of damage caused by snorkellers. At a site with strong currents and shallow water, damage was greater than at a site with deeper water and no current (Ayling & Ayling 1994b). In a separate study designed to investigate the effects of divers on corals, Rouphael & Inglis (1995) found that the impacts of divers were greater in areas dominated by branching *Acropora* than in areas dominated by more robust corals. The data available from pontoons where damage by divers was measured (~3% of corals were damaged in *Acropora* thickets compared with ~4.5% damage outside the *Acropora* thicket) differs from Rouphael & Inglis' findings, but data were far from conclusive.

Further research by Rouphael & Inglis at CRC Reef pursuing the links between divers and damage to corals will help to understand the impacts of divers at pontoons, but there is a need also for more rigorous monitoring of the effects of these activities at pontoon sites. It is not known, for example, what the effect of the damage is on corals, in the short or long term, and what changes occur in benthic community structure as a result of changes in coral cover of specific species or life-forms most prone to damage. Very little is known about the consequences of tissue damage and fragmentation for populations and communities of corals (but see *e.g.*, Meesters & Bak 1993; Van Veghel & Bak 1994). Damage may affect corals in insidious ways. If corals are spending a great deal of energy on repairing damage, they may have less energy to spend on reproduction which may have long-term impacts on coral communities both at the pontoon site (through self-seeding) and elsewhere (through dispersal of larvae). Metabolic costs of repair may also cause decreased rates of growth (Bak 1978; Ward 1995). Fragmentation resulting from fin damage reduces the size of both parent and daughter colonies. Reproduction and survival are both strongly size-dependent (*e.g.*, Babcock 1991; Connell 1973; Hall & Hughes in press; Hughes & Jackson 1985) so continued damage to the same colonies could have cumulative consequences to individuals' fitness. These long-term consequences to population dynamics of corals have not been addressed and need to be considered in future monitoring projects.

Finally, it is still not clear how pontoons affect coral community structure because all studies to date have taken a univariate approach to analysis of patterns. While this approach is valid, investigation of multivariate patterns in coral cover will yield further information about whether the composition of benthic assemblages changes as a result of the installation of a pontoon. Changes in community composition are likely, since corals differ in their susceptibility to disturbances of various kinds. In addition, altering the light regime under a pontoon may affect the composition and abundance of recruits to hard substrata (including the pontoon). If the long-term effects of pontoons are to be understood, these questions should be addressed.

6.3 Impacts of Pontoons on Fish

Fish aggregated at all pontoons. The size and composition of the aggregations varied among pontoons, but there was no evidence of any detrimental effects of the aggregations on other fish, nor was there any evidence of depletion of populations of fish at other locations on the reef. These findings were similar to those of a dedicated study on fish aggregations at pontoons (Sweatman 1996). Sweatman found that aggregations of *Lethrinus nebulosus* and *Lutjanus bohar* (characteristic species in aggregations of fish at pontoons) occurred naturally and that any impacts of aggregations at pontoons were minimal. Given that aggregations appeared to have no detectable effect on local populations, we consider that monitoring of fish aggregations as it stands should not be continued.

6.4 Administration of Pontoon Monitoring

The past 10 years have witnessed considerable efforts by the Great Barrier Reef Marine Park Authority to implement useful impact monitoring programmes for pontoon installations and activities in the Great Barrier Reef Marine Park. As previously noted, however, it was clear from the files, anecdotal evidence, and personal observations that there has been a range of opinion within the Authority about the required form(s) of monitoring and its funding. In the absence of formal, Authority endorsed policy or guidelines, the form of monitoring adopted for each pontoon has apparently been determined by individuals, though there was clearly some consistency of thought on basic principles of monitoring at least within the Research and Monitoring Section of the Authority. These institutional features probably have contributed considerably to the heterogeneity among monitoring programmes for what were essentially 'like' activities. In turn, the dissimilarity among studies has made more difficult the synthesis of results and weakened the value of the monitoring programmes to date as tools of learning about the consequences of pontoon activities. This is probably partly because the programmes were largely overlapping in time, but also suggests a lack of ongoing revision of information within the GBRMPA. It might also reflect changing staff responsible for the project management of pontoon monitoring programmes. There are other possible explanations, but we found no written evidence of them.

The absence of clear written decisions and the rationale(s) for them was likely to have exacerbated the heterogeneity in monitoring designs among pontoons and limited the evolution of coherent pontoon monitoring policy. Formal, consistent guidelines on the monitoring of future, and where feasible present, pontoon installations and associated activities should be developed as soon as possible. We recommend also that technical and logistic features of such monitoring should be prescribed in detail after extensive discussion with relevant scientists, consultants, and tourism operators, and the technical aspects of the final procedures should be thoroughly externally reviewed.

There have been a number of internal discussions of most of the issues surrounding impact monitoring in general, and the monitoring of pontoons in particular. In several cases, however, monitoring programmes were endorsed that have contributed relatively little, or poorly, to the understanding and management of the pontoon associated activities, possibly in the interests of minimising costs to the proponents. Clearly the costs of monitoring impact on the economics of tourism industries, and it is desirable to ensure that monitoring is not excessive. It is critical also, however, that monitoring is sufficient to answer the objectives for which it is sought.

It is important to emphasise here that inexpensive monitoring that has low power may precipitate more problems (in the longer term) than it solves (economically) in the short term. For example, if small to moderate impacts were occurring but monitoring was insensitive to them, there is the risk that a series of (erroneous) conclusions of 'no impact' from weak monitoring programmes would lead to a false sense of complacency about the effects of a nominated type of development, such as pontoon operations. If those accumulated impacts later result in major impacts (that will eventually be detected) then the result may be lost value of the pontoon site, downturn in tourist satisfaction (and visitation), costly re-location of the pontoon, or costly rehabilitation of the site. Fairweather (1991b) emphasises that the long term costs of weak monitoring that results in 'missed' impacts in the short term will almost certainly outweigh the savings gained by short-term savings on the monitoring programme. It is in the interests of both proponents and managers, therefore, to ensure that monitoring is powerful and carefully designed such that the risks of erroneous conclusions are minimised (Mapstone 1995, 1996).

6.5 Recommendations

The following recommendations substantially arise from shortcomings we found in the design, implementation, and management of pontoon monitoring. The list is not exhaustive, as many points about specific issues have been raised already (e.g., the need for more control sites and more frequent monitoring, especially during baseline periods). The suggestions we offer below are intended as a starting point for the refinement of pontoon monitoring procedures.

Adequate objectives must be specified for monitoring. GBRMPA must define why they want to monitor pontoons. The Authority's information needs and expected reaction to perceived impacts should be clearly articulated (Mapstone 1995, Oliver 1995). These should form the basis of specific, detailed objectives for pontoon monitoring. In some cases, it will be necessary to stipulate what size of effect is acceptable or unacceptable for particular activities and their impacts. Consideration should be given to whether the size of an unacceptable impact should be the same at all pontoons, and what criteria might be used to adjust the level of monitoring or acceptable impacts among pontoons. The objectives should specify what variables are of interest.

Baseline monitoring should be improved. Sufficient lead-time must be allowed for adequate monitoring before pontoons are installed. This is a recurrent failing of the past, and should be avoided in the future. It is essential that communication between the IAU and the relevant R&M staff begins as soon as the request for a permit to install or alter a pontoon is received so that preparation for monitoring can begin as early as possible. This would be ensured if R&M staff were included in the permit assessment process from its earliest stages. The Authority has emphasised before that at least 3-6 months should be allowed for design and review of monitoring proposals, and that at least 2 baseline surveys should be done. Neither has happened routinely. Proponents must be made aware of these requirements.

Core monitoring procedures should be standardised. The Authority should consider adopting a standard set of 'core' monitoring procedures, properly designed, with standard methods, and targeted at specific standard activities for application to all pontoons. The designs might need to be modular, with components added or removed according to what activities are conducted at each pontoon. Properly designed and reviewed, these standard components could then be applied without separate review for each new pontoon, with the result that lead-time would be reduced and consistency of data among pontoons would be increased. Prescription of each component might also include detailed description of the methods of data collection and analysis. It is clear from the reports we reviewed that analyses are often mistaken.

Design details should be developed with appropriate consultation. Monitoring design and operational details should draw on the expertise and goodwill of relevant scientists, consultants, and pontoon operators. It is unreasonable to expect Authority staff, or anyone else, to be masters of all the information relevant to the optimum design of monitoring, though ultimately the Authority will be responsible for the final product. Mapstone (1995, 1996) and Keough & Mapstone (1995) have recommended that proponents, managers, and relevant interested parties should negotiate the specific terms of monitoring at several stages, including:

- ?? The statement of objectives. Whilst the Authority must get information it needs for management, it is important that specified objectives are achievable, as well as desirable. Technical expertise may be required here, as well as sound knowledge of exactly how activities at pontoons are run.
- ?? Criteria by which decisions about impacts are made. This might include agreement among the Authority, proponents, consultants, and scientists on the decision making procedures, including statistical decision rules. Mapstone (1995, 1996) argued that interested parties should agree on acceptable levels of Type I and Type II error prior to finalising the design of monitoring. Type I error rate is the probability of falsely detecting an impact when in truth there is none, and is traditionally set at 0.05. A small Type I error rate avoids false alarms, but will usually be associated with a large potential for Type II error. Type II error is the probability of failing to detect an impact when there is one. This type of error is potentially more damaging both to the environment and to the pontoon operator's business because a real impact remains undetected. Type II error is often ignored during the design process. Clearly acceptable levels of both Type I and Type II errors should be specified in advance in relation to the costs to the proponent and the environment.

Enhancement of monitoring through closer collaboration with tourist operations should be considered. The Authority should discuss with pontoon operators the potential for consultants to conduct more frequent monitoring unobtrusively during routine daily trips to pontoons. For example, it may be feasible for monitoring damage to corals at snorkel or dive sites and control sites to be done within the period of a usual trip to a pontoon. With careful design, such monitoring would take maximum advantage of the daily access to pontoons provided by tourist operations. This may reduce substantially the added costs to the proponent of monitoring programmes, and also increase the frequency and relevance of data. The pontoon operations potentially provide unparalleled access for monitoring impacts, but to date that access seems not to have been used to the advantage of either the proponents, consultants, or the Authority.

Full review of monitoring procedures should be considered every 3-5 years. The progress of monitoring should be reviewed periodically, and refined or updated in the context of what has been learned about specific impacts in relation to recent research. The Authority should take better advantage of the expertise of reviewers. The reviewers often have sensible suggestions about issues of general relevance or technical detail, not only of relevance to particular proposals and reports. Many of the criticisms we have made in this document have previously been made by reviewers. These comments should be taken into consideration when re-visiting the requirements of pontoon monitoring. The system of frequent external review of proposals and reports is a commendable one, but will be improved considerably if the Authority implements a structured strategy for incorporating relevant comments from reviewers into subsequent monitoring programmes. It is highly desirable that between such reviews monitoring should remain as consistent as possible.

General purpose monitoring should be reduced. Sufficient is now known about the specific activities associated with pontoons, and the most likely form(s) of their impacts, for the Authority to refine monitoring from the general, omnibus monitoring of the past to more specific monitoring. Future monitoring should be highly targeted, with designs tailored to the requirements of assessing specific types of impacts.

Higher priority should be given to the soundness of monitoring design. This should include adequate baseline monitoring (with more than 2 sampling times), sufficient control sites (generally >3), and formal verification that the results of proposed monitoring will be powerful and rigorous against specified limits of acceptable change (Oliver 1995), both individually and collectively.

Independence of Consultants and Proponents should be maintained. The Authority has developed a sound working model for the management of impact monitoring such that maximum independence between proponents and consultants is maintained. This procedure should not be relaxed under any circumstances. Thorough external reviewing of proposals (but see **F** above) and reports is integral to ensuring proper independent assessment of monitoring procedures and results, and the Authority's existing procedures should be retained in-tact.

Justification for decisions should be fully documented. It was often unclear why particular courses of action were adopted either during monitoring programmes or between one programme and the next. For example, it was apparent in places either that reviewers comments had been ignored or that specific decisions had been taken against the recommendations of reviewers, but there was no evidence which was the case. The absence of clear documentation of decisions and actions taken during management of monitoring programmes militates against coherent learning from one project to the next, increases the potential for individuals interpretations rather than application of formal policy to drive monitoring practice, and diminishes the links between monitoring results and management of pontoons. Rigorous documentation of decision in the management of monitoring programmes will ensure that the decision-making process is transparent, accountable, and defensible, as well as providing a clear template on which future decisions can build.

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Appendix 1

Reanalysis of studies on the effects of the pontoon footprint

Agincourt 3a

Total Hard corals / **Soft Corals**

Source of Variation	df	MS	F	p	MS	F	p
Between Subjects							
Impact vs Control	1	99994.13	1.15	0.362	3763.2	2.72	0.197
Site(Control)	3	86965.52	3.9	0.024	1381.1	5.1	0.009
Residual(Site)	20	22317.77			270.82		
Within Subjects							
Time	2	1017.23	0.07	0.933	25.9	1.36	0.326
Imp-Cont*Time	2	2454.43	0.17	0.851	16.9	0.89	0.46
Site(Control)*Time	6	14784.09	1.73	0.139	19.05	0.38	0.885
Residual(Time)	40	8536.28			49.63		

Acroporids / **Algae**

Source of Variation	df	MS	F	p	MS	F	p
Between Subjects							
Impact vs Control	1	55212.30	0.81	0.434	464.13	1.77	0.275
Site(Control)	3	67982.37	6.07	0.004	261.69	1.99	0.148
Residual(Site)	20	11198.98			131.57		
Within Subjects							
Time	2	468.93	0.417	0.677	382.03	1.28	0.309
Imp-Cont*Time	2	1369.20	1.22	0.36	844.63	2.82	0.151
Site(Control)*Time	6	1123.83	1.11	0.372	299.08	2.06	0.08
Residual(Time)	40	1008.93			145.16		

Pocilloporids

Source of Variation	df	MS	F	p
Between Subjects				
Impact vs Control	1	2520.83	0.75	0.451
Site(Control)	3	3377.14	3.54	0.033
Residual(Site)	20	955.03		
Within Subjects				
Time	2	188.03	0.25	0.787
Imp-Cont*Time	2	29.43	0.04	0.962
Site(Control)*Time	6	763.75	1.43	0.226
Residual(Time)	40	533.09		

Poritids

Source of Variation	df	MS	F	p
Between Subjects				
Impact vs Control	1	6571.20	8.7	0.06
Site(Control)	3	755.36	0.66	0.587
Residual(Site)	20	1146.15		
Within Subjects				
Time	2	596.80	1.56	0.298
Imp-Cont*Time	2	439.60	1.15	0.388
Site(Control)*Time	6	382.03	1.27	0.294
Residual(Time)	40	301.59		

Faviids

Source of Variation	df	MS	F	p
Between Subjects				
Impact vs Control	1	6541.63	0.35	0.598
Site(Control)	3	18889.93	8.35	0.001
Residual(Site)	20	222.89		
Within Subjects				
Time	2	97.60	0.28	0.767
Imp-Cont*Time	2	140.93	0.41	0.684
Site(Control)*Time	6	342.57	0.63	0.63
Residual(Time)	40	547.41		

Appendix 1

Reanalysis of studies on the effects of the pontoon footprint

Agincourt 4 Reef

Total Hard Corals / Soft Corals

Source of Variation	df	MS	F	*p*	Soft Corals MS	F	*p*
Between Subjects							
Impact vs Control	1	0.29	0	0.987	0.38	0.05	0.834
Site(Control)	3	940.01	5.38	0.006	7.38	1.34	0.285
Residual(Site)	24	174.80			5.51		
Within Subjects							
Time	2	373.95	7.61	0.03	1.55	2.18	0.208
Imp-Cont*Time	2	29.73	0.61	0.579	1.61	2.26	0.2
Site(Control)*Time	6	49.13	1.53	0.189	0.71	0.51	0.801
Residual(Time)	48	32.16			1.41		

Acroporids / Algae

Source of Variation	df	MS	F	*p*	Algae MS	F	*p*
Between Subjects							
Impact vs Control	1	201.74	0.47	0.541	9.68	2.2	0.235
Site(Control)	3	426.57	2.67	0.071	4.4	1.47	0.248
Residual(Site)	24	159.93			3		
Within Subjects							
Time	2	1.79	0.17	0.847	4.65	1.28	0.344
Imp-Cont*Time	2	2.54	0.24	0.795	5.58	1.54	0.289
Site(Control)*Time	6	10.4	0.58	0.715	3.63	1.21	0.318
Residual(Time)	48	18.01			3		

Pocilloporids

Source of Variation	df	MS	F	*p*
Between Subjects				
Impact vs Control	1	0.25	0.02	0.901
Site(Control)	3	13.56	3.33	0.036
Residual(Site)	24	4.07		
Within Subjects				
Time	2	0.24	0.31	0.747
Imp-Cont*Time	2	0.29	0.37	0.708
Site(Control)*Time	6	0.77	0.88	0.519
Residual(Time)	48	0.87		

Poritids

Source of Variation	df	MS	F	*p*
Between Subjects				
Impact vs Control	1	12.97	0.01	0.927
Site(Control)	3	1314.57	5.38	0.006
Residual(Site)	24	244.54		
Within Subjects				
Time	2	286.46	8.63	0.024
Imp-Cont*Time	2	18.84	0.57	0.598
Site(Control)*Time	6	33.21	2.2	0.06
Residual(Time)	48	15.13		

Faviids

Source of Variation	df	MS	F	*p*
Between Subjects				
Impact vs Control	1	16.65	0.16	0.718
Site(Control)	3	105.62	2.49	0.085
Residual(Site)	24	42.5		
Within Subjects				
Time	2	3.49	0.91	0.452
Imp-Cont*Time	2	9.8	2.56	0.157
Site(Control)*Time	6	3.82	2.46	0.037
Residual(Time)	48	1.55		

Appendix 2

Reanalysis of studies on the effects of snorkellers

Agincourt 4 Reef

Total Hard Corals / Soft Corals

Source of Variation	df	MS	F	p	MS (Soft Corals)	F (Soft Corals)	p (Soft Corals)
Between Subjects							
Impact vs Control	1	103.36	0.18	0.703	4.48	2.37	0.222
Site(Control)	3	587.75	5.03	0.008	1.89	0.08	0.968
Residual(Site)	24	116.78			22.73		
Within Subjects							
Time	2	88.04	1.56	0.285	0.06	0.06	0.942
Imp-Cont*Time	2	31.76	0.56	0.597	1.23	1.26	0.348
Site(Control)*Time	6	56.51	3.11	0.012	0.98	0.76	0.608
Residual(Time)	48	18.14			1.29		

Acroporids / Algae

Source of Variation	df	MS	F	p	MS (Algae)	F (Algae)	p (Algae)
Between Subjects							
Impact vs Control	1	114.13	1.84	0.268	0.67	0.03	0.878
Site(Control)	3	62	0.75	0.532	23.93	4.71	0.01
Residual(Site)	24	82.45			5.08		
Within Subjects							
Time	2	104.48	3.1	0.133	2.91	1.1	0.402
Imp-Cont*Time	2	7.61	0.23	0.803	8.49	3.21	0.127
Site(Control)*Time	6	33.7	4.03	0.002	2.64	0.34	0.914
Residual(Time)	48	8.35			7.83		

Pocilloporids

Source of Variation	df	MS	F	p
Between Subjects				
Impact vs Control	1	0.84	0.11	0.758
Site(Control)	3	7.36	1.46	0.25
Residual(Site)	24	5.03		
Within Subjects				
Time	2	2.44	1.81	0.243
Imp-Cont*Time	2	1.03	0.76	0.508
Site(Control)*Time	6	1.35	1.29	0.278
Residual(Time)	48	1.04		

Poritids

Source of Variation	df	MS	F	p
Between Subjects				
Impact vs Control	1	0.34	0	0.973
Site(Control)	3	247.99	11.52	0
Residual(Site)	24	21.52		
Within Subjects				
Time	2	0.16	0.19	0.832
Imp-Cont*Time	2	0.23	0.27	0.769
Site(Control)*Time	6	0.84	0.43	0.858
Residual(Time)	48	1.98		

Faviids

Source of Variation	df	MS	F	p
Between Subjects				
Impact vs Control	1	265.69	1.98	0.254
Site(Control)	3	134.02	4.78	0.009
Residual(Site)	24	28.01		
Within Subjects				
Time	2	1.2	0.55	0.608
Imp-Cont*Time	2	7.66	3.53	0.111
Site(Control)*Time	6	2.17	1.46	0.211
Residual(Time)	48	1.48		

Appendix 2

Reanalysis of studies on the effects of snorkellers

Hardy Reef

Total Hard Corals

Source of Variation	df	MS	F	*p*
Between Subjects				
Impact vs Control	1	1012.7	0.89	0.518
Site(Control)	1	1134.48	2.43	0.13
Residual(Site)	27	465.92		
Within Subjects				
Time	2	69.8	4.14	0.291
Imp-Cont*Time	2	15.63	0.93	0.512
Site(Control)*Time	2	16.84	1.74	0.185
Residual(Time)	54	9.68		

Soft Corals

Source of Variation	MS	F	*p*
Between Subjects			
Impact vs Control	10.17	0.03	0.897
Site(Control)	380.52	2.33	0.139
Residual(Site)	163.64		
Within Subjects			
Time	9.95	2.35	0.368
Imp-Cont*Time	3.88	0.92	0.513
Site(Control)*Time	4.24	0.43	0.653
Residual(Time)	9.87		

Acroporids

Source of Variation	df	MS	F	*p*
Between Subjects				
Impact vs Control	1	914.94	0.69	0.558
Site(Control)	1	1318.83	3.15	0.087
Residual(Site)	27	418.95		
Within Subjects				
Time	2	25.99	0.93	0.512
Imp-Cont*Time	2	4.41	0.16	0.758
Site(Control)*Time	2	27.85	4.74	0.013
Residual(Time)	54	5.88		

Algae

Pocilloporids

Source of Variation	df	MS	F	*p*
Between Subjects				
Impact vs Control	1	28.29	2.29	0.371
Site(Control)	1	12.33	1.31	0.262
Residual(Site)	27	9.39		
Within Subjects				
Time	2	0.38	0.51	0.605
Imp-Cont*Time	2	1.12	1.51	0.435
Site(Control)*Time	2	0.74	1.53	0.225
Residual(Time)	54	0.48		

Damage

Source of Variation	MS	F	*p*
Between Subjects			
Impact vs Control	58.61	181.64	0.047
Site(Control)	0.32	0.09	0.767
Residual(Site)	3.6		
Within Subjects			
Time	31.94	159.7	0.05
Imp-Cont*Time	29.2	145.9	0.053
Site(Control)*Time	0.2	0.13	0.878
Residual(Time)	1.51		

Poritids

Source of Variation	df	MS	F	*p*
Between Subjects				
Impact vs Control	1	6.7	157.03	0.051
Site(Control)	1	0.04	0	0.946
Residual(Site)	27	9.1		
Within Subjects				
Time	2	0.67	0.27	0.695
Imp-Cont*Time	2	1.57	0.62	0.575
Site(Control)*Time	2	2.52	4.29	0.019
Residual(Time)	54	0.59		

Height

Source of Variation	MS	F	*p*
Between Subjects			
Impact vs Control	27093.75	1.49	0.437
Site(Control)	18200.42	0.68	0.418
Residual(Site)	26861.28		
Within Subjects			
Time	1305.32	1.79	0.313
Imp-Cont*Time	2502.35	3.42	0.206
Site(Control)*Time	731.27	1.3	0.28
Residual(Time)	560.63		

Faviids

Source of Variation	df	MS	F	*p*
Between Subjects				
Impact vs Control	1	7.92	1.79	0.409
Site(Control)	1	4.43	0.29	0.597
Residual(Site)	27	15.48		
Within Subjects				
Time	2	4.51	6.09	0.245
Imp-Cont*Time	2	0.04	0.06	0.847
Site(Control)*Time	2	0.74	0.93	0.402
Residual(Time)	54	0.79		

Appendix 2

Reanalysis of studies on the effects of snorkellers

Moore GA Reef (non-Acropora thicket)

Total Hard Corals **Source of Variation**	**df**	**MS**	**F**	***p***	**Soft Corals** **MS**	**F**	***p***
Between Subjects							
Impact vs Control	1	581.68	38.48	0.102	0.25	0	0.974
Site(Control)	1	15.12	0.11	0.745	150.98	3.55	0.084
Residual(Site)	12	136.55			42.53		
Within Subjects							
Time	2	568.6	9.61	0.094	4.11	1.34	0.427
Imp-Cont*Time	2	4.51	0.08	0.926	0.09	0.003	0.971
Site(Control)*Time	2	59.19	5.24	0.013	3.06	2.08	0.147
Residual(Time)	24	11.3			1.47		

Acroporids **Source of Variation**	**df**	**MS**	**F**	***p***	**Algae** **MS**	**F**	***p***
Between Subjects							
Impact vs Control	1	627	56.17	0.084	0.85	0.54	0.596
Site(Control)	1	11.16	0.08	0.78	1.56	0.68	0.427
Residual(Site)	12	137.21			2.32		
Within Subjects							
Time	2	464.64	9.99	0.091	1.74	4.05	0.365
Imp-Cont*Time	2	2.29	0.05	0.952	0.34	0.79	0.746
Site(Control)*Time	2	46.53	4.44	0.023	0.43	0.59	0.562
Residual(Time)	24	10.48			0.73		

Pocilloporids **Source of Variation**	**df**	**MS**	**F**	***p***	**Damage** **MS**	**F**	***p***
Between Subjects							
Impact vs Control	1	5.55	0.29	0.688	12.98	3.09	0.329
Site(Control)	1	19.44	4.52	0.055	4.2	4.17	0.064
Residual(Site)	12	4.3			1.01		
Within Subjects							
Time	2	4.4	1.67	0.375	1.82	4.33	0.188
Imp-Cont*Time	2	2.06	0.78	0.561	0.9	2.13	0.319
Site(Control)*Time	2	2.63	3.31	0.054	0.42	0.45	0.645
Residual(Time)	24	0.79			0.94		

Poritids **Source of Variation**	**df**	**MS**	**F**	***p***	**Height** **MS**	**F**	***p***
Between Subjects							
Impact vs Control	1	38.53	116.5	0.059	27093.75	1.49	0.437
Site(Control)	1	0.33	0.05	0.823	18200.42	0.68	0.418
Residual(Site)	12	6.34			26861.28		
Within Subjects							
Time	2	0.12	0.92	0.521	1305.32	1.79	0.313
Imp-Cont*Time	2	0.18	1.38	0.42	2502.35	3.42	0.206
Site(Control)*Time	2	0.13	1.68	0.208	731.27	1.3	0.28
Residual(Time)	24	0.08			560.63		

Faviids **Source of Variation**	**df**	**MS**	**F**	***p***
Between Subjects				
Impact vs Control	1	5.33	0.1	0.805
Site(Control)	1	53.47	3.2	0.099
Residual(Site)	12	16.7		
Within Subjects				
Time	2	0.09	1.13	0.469
Imp-Cont*Time	2	0.23	2.76	0.266
Site(Control)*Time	2	0.08	0.18	0.836
Residual(Time)	24	0.45		

Appendix 2

Reanalysis of studies on the effects of snorkellers

Moore GA Reef (Acropora thicket)

Total Hard Corals: Source of Variation	df	MS	F	*p*	Soft Corals: MS	F	*p*
Between Subjects							
Impact vs Control	1	1888.13	1.38	0.449	15.84	0.23	0.713
Site(Control)	1	1371.6	12.87	0.004	67.8	10.55	0.007
Residual(Site)	12	106.57			6.43		
Within Subjects							
Time	2	192.68	9.83	0.092	4.18	2.08	0.325
Imp-Cont*Time	2	16.07	0.82	0.55	3.91	1.95	0.339
Site(Control)*Time	2	19.61	1.1	0.348	2.01	4.69	0.019
Residual(Time)	24	17.79			0.43		

Acroporids: Source of Variation	df	MS	F	*p*	Algae: MS	F	*p*
Between Subjects							
Impact vs Control	1	2628.29	1.44	0.442	8.86	18.4	0.146
Site(Control)	1	1818.97	15.66	0.002	0.48	0.09	0.768
Residual(Site)	12	113.78			5.28		
Within Subjects							
Time	2	180.38	10.49	0.087	10.16	508	0.002
Imp-Cont*Time	2	12.16	0.71	0.585	0.37	17.11	0.055
Site(Control)*Time	2	17.2	0.9	0.42	0.02	0.01	0.987
Residual(Time)	24	19.13			1.63		

Pocilloporids: Source of Variation	df	MS	F	*p*	Damage: MS	F	*p*
Between Subjects							
Impact vs Control	1	0.06	0.01	0.939	0.17	0.15	0.766
Site(Control)	1	6.67	2.68	0.127	1.14	1.68	0.219
Residual(Site)	12	2.49			0.68		
Within Subjects							
Time	2	0.37	2.31	0.302	3.03	6.18	0.139
Imp-Cont*Time	2	0.09	0.58	0.633	2.69	5.5	0.154
Site(Control)*Time	2	0.16	0.45	0.645	0.49	0.49	0.618
Residual(Time)	24	0.35			0.99		

Poritids: Source of Variation	df	MS	F	*p*	Height: MS	F	*p*
Between Subjects							
Impact vs Control	1	98.28	1.48	0.438	2245162	34.12	0.108
Site(Control)	1	66.31	2.71	0.125	65800.83	1.87	0.197
Residual(Site)	12	24.42			35214.74		
Within Subjects							
Time	2	0.07	0.58	0.633	14721.1	1.24	0.446
Imp-Cont*Time	2	0.41	3.6	0.217	1000.03	0.08	0.926
Site(Control)*Time	2	0.12	0.1	0.904	11847.43	0.25	0.777
Residual(Time)	24	1.14			46577.64		

Faviids: Source of Variation	df	MS	F	*p*
Between Subjects				
Impact vs Control	1	1.75	0.92	0.513
Site(Control)	1	1.9	0.43	0.523
Residual(Site)	12	4.4		
Within Subjects				
Time	2	0.16	4	0.2
Imp-Cont*Time	2	0.09	2.33	0.3
Site(Control)*Time	2	0.04	0.6	0.559
Residual(Time)	24	0.07		

Appendix 3

Reanalysis of studies on the effects of divers

Hardy Reef

	Total Hard Corals				Soft Corals		
Source of Variation	**df**	**MS**	**F**	***p***	**MS**	**F**	***p***
Between Subjects							
Impact vs Control	1	0.47	0	0.99	6.34	0.02	0.917
Site(Control)	1	1763.67	4.42	0.045	370.02	3.6	0.0699
Residual(Site)	27	398.86			102.85		
Within Subjects							
Time	2	33.94	13.21	0.171	15.15	1.14	0.479
Imp-Cont*Time	2	16.3	6.34	0.241	7.88	0.59	0.583
Site(Control)*Time	2	2.57	0.25	0.783	13.32	1.72	0.188
Residual(Time)	54	10.47			7.72		

	Acroporids				Algae		
Source of Variation	**df**	**MS**	**F**	***p***			
Between Subjects							
Impact vs Control	1	19.49	0.04	0.876			
Site(Control)	1	499.97	2.55	0.122			
Residual(Site)	27	196.26					
Within Subjects							
Time	2	5.16	0.77	0.541			
Imp-Cont*Time	2	2.55	0.38	0.648			
Site(Control)*Time	2	6.71	1.09	0.343			
Residual(Time)	54	6.14					

	Pocilloporids				Damage		
Source of Variation	**df**	**MS**	**F**	***p***	**MS**	**F**	***p***
Between Subjects							
Impact vs Control	1	2.52	19.3	0.142	48.96	11750.56	0.006
Site(Control)	1	0.13	0.02	0.897	0	0	0.971
Residual(Site)	27	7.69			3.18		
Within Subjects							
Time	2	1.46	3.84	0.3	26.43	31.46	0.112
Imp-Cont*Time	2	0.52	1.36	0.451	11.15	13.35	0.17
Site(Control)*Time	2	0.38	1.45	0.245	0.84	0.55	0.528
Residual(Time)	54	0.26			1.51		

	Poritids				Height		
Source of Variation	**df**	**MS**	**F**	***p***	**MS**	**F**	***p***
Between Subjects							
Impact vs Control	1	9.28	0.01	0.931	63375	1.65	0.421
Site(Control)	1	774.72	4.58	0.042	38405.4	0.92	0.345
Residual(Site)	27	169.15			41581.61		
Within Subjects							
Time	2	2.46	4.73	0.274	20148.27	5.64	0.141
Imp-Cont*Time	2	1.68	3.24	0.323	1256.6	0.35	0.614
Site(Control)*Time	2	0.52	0.27	0.763	3571.2	1.41	0.254
Residual(Time)	54	1.9			2540.55		

Faviids

Source of Variation	df	MS	F	*p*
Between Subjects				
Impact vs Control	1	0.36	0.03	0.898
Site(Control)	1	13.87	0.19	0.664
Residual(Site)	27	71.74		
Within Subjects				
Time	2	3.92	4.4	0.283
Imp-Cont*Time	2	0.32	0.36	0.656
Site(Control)*Time	2	0.89	0.79	0.458
Residual(Time)	54	1.12		

Appendix 3

Reanalysis of studies on the effects of divers

Moore GA Reef (non-Acropora thicket)

Source of Variation	df	Total Hard Corals MS	Total Hard Corals F	Total Hard Corals p	Soft Corals MS	Soft Corals F	Soft Corals p
Between Subjects							
Impact vs Control	1	2042.7	2.43	0.363	0.28	0.02	0.919
Site(Control)	1	840.58	1.57	0.235	16.95	0.81	0.385
Residual(Site)	12	536.55			20.81		
Within Subjects							
Time	2	142.08	19.96	0.007	3.73	18.65	0.051
Imp-Cont*Time	2	2.44	0.34	0.745	1.28	6.33	0.136
Site(Control)*Time	2	7.12	0.85	0.44	0.2	0.19	0.825
Residual(Time)	24	8.38			1.04		

Source of Variation	df	Acroporids MS	Acroporids F	Acroporids p	Algae MS	Algae F	Algae p
Between Subjects							
Impact vs Control	1	612.01	0.57	0.59	14.28	19.4	0.142
Site(Control)	1	1083	3.69	0.079	0.74	0.21	0.653
Residual(Site)	12	293.15			3.46		
Within Subjects							
Time	2	90.75	8.28	0.108	0.28	0.11	0.901
Imp-Cont*Time	2	0.22	0.02	0.98	0.47	0.19	0.84
Site(Control)*Time	2	10.96	1.36	0.276	2.45	2.1	0.144
Residual(Time)	24	8.04			1.17		

Source of Variation	df	Pocilloporids MS	Pocilloporids F	Pocilloporids p	Damage MS	Damage F	Damage p
Between Subjects							
Impact vs Control	1	0.03	0	0.974	75.72	11732.83	0.006
Site(Control)	1	18.02	9.96	0.008	0.01	0	0.947
Residual(Site)	12	1.81			1.41		
Within Subjects							
Time	2	0.29	0.55	0.645	0.97	large no	0
Imp-Cont*Time	2	0.03	0.05	0.949	0.13	57.19	0.017
Site(Control)*Time	2	0.53	2.99	0.069	0	0	0.998
Residual(Time)	24	0.18			1.44		

Source of Variation	df	Poritids MS	Poritids F	Poritids p	Height MS	Height F	Height p
Between Subjects							
Impact vs Control	1	568.98	41.02	0.099	4017948	1.17	0.475
Site(Control)	1	13.87	0.02	0.882	0.3430701	91.64	0
Residual(Site)	12	608.35			37436.49		
Within Subjects							
Time	2	6.82	2.75	0.267	19239.63	1844.64	0.0005
Imp-Cont*Time	2	3.29	1.33	0.429	855.83	82.03	0.012
Site(Control)*Time	2	2.48	0.97	0.393	10.43	0	1
Residual(Time)	24	2.55			21683.92		

Faviids

Source of Variation	df	MS	F	p
Between Subjects				
Impact vs Control	1	3.57	7.04	0.229
Site(Control)	1	0.51	0.04	0.844
Residual(Site)	12	12.48		
Within Subjects				
Time	2	0.23	1	0.5
Imp-Cont*Time	2	0.53	2.27	0.306
Site(Control)*Time	2	0.23	1.58	0.227
Residual(Time)	24	0.15		

Appendix 3

Reanalysis of studies on the effects of divers

Moore GA Reef (Acropora thicket)

	Total Hard Corals				Soft Corals		
Source of Variation	**df**	**MS**	**F**	***p***	**MS**	**F**	***p***
Between Subjects							
Impact vs Control	1	141.48	97.44	0.064	22.88	0.74	0.547
Site(Control)	1	1.45	0	0.962	30.81	1.77	0.208
Residual(Site)	12	624.89			17.41		
Within Subjects							
Time	2	214.91	165.32	0.006	11.26	12.37	0.075
Imp-Cont*Time	2	13.8	10.61	0.086	1.65	1.81	0.356
Site(Control)*Time	2	1.3	0.12	0.887	0.91	0.84	0.442
Residual(Time)	24	10.82			1.08		

	Acroporids				Algae		
Source of Variation	**df**	**MS**	**F**	***p***	**MS**	**F**	***p***
Between Subjects							
Impact vs Control	1	528.36	17.38	0.15	0.02	25	0.126
Site(Control)	1	30.4	0.05	0.832	0	0	0.986
Residual(Site)	12	643.45			2.44		
Within Subjects							
Time	2	183.22	508.94	0.002	8.73	3.04	0.247
Imp-Cont*Time	2	10.45	29.03	0.033	0.01	0	1
Site(Control)*Time	2	0.36	0.03	0.97	2.87	1.57	0.229
Residual(Time)	24	12.03			1.83		

	Pocilloporids				Damage		
Source of Variation	**df**	**MS**	**F**	***p***	**MS**	**F**	***p***
Between Subjects							
Impact vs Control	1	1.88	8.01	0.216	34.09	20.69	0.138
Site(Control)	1	0.23	0.04	0.843	1.65	1.88	0.196
Residual(Site)	12	5.68			0.88		
Within Subjects							
Time	2	0.41	1.86	0.35	0.37	0.65	0.606
Imp-Cont*Time	2	0.27	1.24	0.446	1.87	3.28	0.234
Site(Control)*Time	2	0.22	0.63	0.54	0.57	0.46	0.637
Residual(Time)	24	0.35			1.25		

	Poritids				Height		
Source of Variation	**df**	**MS**	**F**	***p***	**MS**	**F**	***p***
Between Subjects							
Impact vs Control	1	56.44	0.69	0.559	288316	0.23	0.718
Site(Control)	1	81.84	5.79	0.033	1277616	34.01	0
Residual(Site)	12	14.13			37562.94		
Within Subjects							
Time	2	0.02	0.18	0.847	46416.4	0.66	0.602
Imp-Cont*Time	2	0.04	0.37	0.73	3613.33	0.05	0.952
Site(Control)*Time	2	0.11	0.46	0.637	70775.43	1.66	0.21
Residual(Time)	24	0.24			42529.31		

Faviids

Source of Variation	**df**	**MS**	**F**	***p***
Between Subjects				
Impact vs Control	1	6.03	2.97	0.335
Site(Control)	1	2.03	0.49	0.499
Residual(Site)	12	4.17		
Within Subjects				
Time	2	0.2	0.8	0.556
Imp-Cont*Time	2	0.24	0.95	0.513
Site(Control)*Time	2	0.25	2.78	0.082
Residual(Time)	24	0.09		