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Assessing the effects of logging on coral reefs in Solomon Islands

T.F. Cooper¹, M.P. Lincoln Smith², J.D. Bell¹ and K.A. Pitt¹

ABSTRACT

The corals occurring in bays adjacent to mouths of rivers in Western Province, Solomon Islands, are being studied to quantify the effects of runoff associated with logging on coral reefs. The 5-year study aims to identify any effects of runoff on fringing coral reefs by comparing abundance, diversity, survival and recruitment of corals adjacent to actively logged, previously logged and unlogged catchments on each of 2 islands. A pilot study comparing diversity and abundance of corals adjacent to actively logged and unlogged catchments indicated that effects of runoff on corals did not always conform to predictions, and differed between islands. For example, there was more dead coral adjacent to logged catchments at Vangunu Island, whereas at Kolombangara Island, more live coral occurred adjacent to actively logged catchments. The comparison of bays adjacent to actively logged, previously logged and unlogged catchments over 5 years is expected to provide a robust test of any effects of runoff on diversity and abundance of corals, whilst also testing for recovery from any such impacts.

Keywords Runoff, Sedimentation, Experimental design, Environmental impact

Introduction

Sedimentation from natural and anthropogenic sources (e.g. runoff associated with logging) can have a number of effects on the community structure of coral reefs (Loya 1976, Sakai and Nishihira 1991). Direct effects of sedimentation on corals include mortality due to burial (Marshall and Orr 1931), reduced growth due to abrasion by suspended sediments (Loya 1976), modification of coral morphology (Marshall and Orr 1931), changes to species abundance and diversity (Dodge and Vaisnys, 1977, Brown et al. 1990), reduced levels of coral recruitment (Hodgson 1990, Babcock and Davies 1991, Te 1992, Maida et al. 1994) and a reduced area of live coral cover (Rogers 1990). Indirect effects include a disruption of energy budgets of corals due to a reduction in the amount of light available for photosynthesis in zooxanthellae (Roy and Smith 1971), effects on filter feeding mechanisms and a diversion of energy from growth to active sediment rejection (Stafford-Smith and Ormond 1992). In turn, these effects on coral assemblages have the potential to adversely affect humans who rely on aquatic resources, e.g. nearshore fisheries, for survival.

The export of whole logs from tropical rainforests has been a major source of foreign earnings for developing island nations in the Western Pacific, particularly Vanuatu, Papua New Guinea and Solomon Islands. Surface runoff associated with periods of high rainfall may occur in undisturbed habitats, however, the removal of vegetation and the reduction in soil permeability, associated with soil compaction during logging operations, increases the erosive effects of surface runoff (Campbell and Doeg 1989). The economic benefits that stem from exploitation of this natural resource are, however, potentially offset by the negative effects of

runoff on the physical and biological structure of freshwater streams and the receiving marine waters into which they flow.

The aim of the study was to quantify the effects of runoff associated with logging on coral reefs by comparing coral reef habitats, coral growth morphology and taxonomic composition between actively logged and unlogged areas.

Currently accepted best practice in ecological monitoring includes the comparison of data collected before and after the putative impact occurs at the site of the disturbance and at several control sites (Green 1979, Underwood 1991). This type of sampling is known as a BACI (Before-After, Control-Impact) design. In this study, it has not been possible to sample sites before the logging commenced, so it has not been possible to use the BACI approach.

In the absence of the before data needed for a BALI design, an appropriate way to gauge any effects of logging is to compare the aquatic habitats and biota from at least two logged and at least two unlogged catchments (Green 1979, Glasby 1997). This type of sampling design is known as a hierarchical or nested design, because it compares logged versus unlogged areas and catchments nested within each of these two types of areas (Fig. 1a). Provided two or more catchments are sampled in each category, it is possible to determine whether differences between logged and unlogged catchments are greater than differences within logged, or unlogged, catchments. The main study design of this project will incorporate a third study treatment (previously logged catchments), but only logged and unlogged catchments, i.e. the most extreme situation, were examined during the pilot study. The broad hypothesis tested was that coral reef habitats, growth morphology and taxonomic composition would differ in bays adjacent to rivers with logged catchments compared to those in the receiving waters of unlogged catchments.

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Methods

Two islands were identified in the Western Province of Solomon Islands that contained actively logged and unlogged catchments (Fig. 2). These were Kolombangara Island ($8^{\circ} 0'S$, $157^{\circ} 0'E$), where plantation logging occurs, and Vangunu Island ($8^{\circ} 30'S$, $158^{\circ} 0'E$), where logs are extracted from virgin forest areas. Both islands are volcanic in origin with steep slopes and heavily vegetated catchments. Catchment size ranged from 15 km^2 to 29 km^2 on Kolombangara Island and 4 km^2 to 9 km^2 on Vangunu Island. Human activities other than logging within the catchments are limited to small scale subsistence farming by coastal communities.

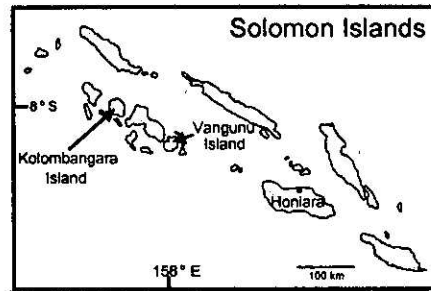


Fig. 2. Map of study islands in the Western Province, Solomon Islands.

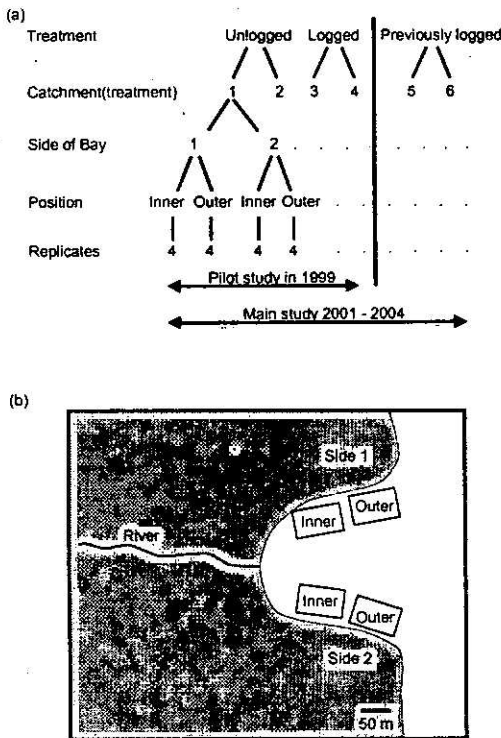


Fig. 1a. Experimental design used to assess the effects of runoff associated with logging on coral reefs in Solomon Islands. Note that only bays adjacent to actively logged and unlogged catchments were sampled during the pilot study in May 1999. Fig. 1b. Schematic illustration showing partitioning at different spatial scales of coral reefs in bays adjacent to each type of catchment.

There were geographical differences between islands which would confound the comparison of logging operations between islands, e.g. some study sites at Vangunu Island occurred in the protected environment of Marovo Lagoon whereas the study sites at Kolombangara Island occurred in an open coastal environment, so separate comparisons of logged and unlogged catchments were done for each island. All sampling was done in May 1999.

All data were collected using a point intercept technique to estimate percentage cover. Scuba divers swam along 20 m transects and recorded data at 0.5 m intervals. Four transects were laid at an inner and outer position on both sides of two bays adjacent to logged and unlogged catchments (Fig. 1b). The inner and outer positions were separated by a distance of approximately 20 m. It was necessary to partition each bay at different spatial scales, i.e. sides and positions, because the movement of the plume of sediment did not appear to be uniform throughout the bay. The types of data collected were divided into 3 categories: coral reef habitat (live coral, dead *Porites*, dead *Acropora*, other dead coral, coral rubble, sand, silt and macro-algae); growth morphology (branching, massive, foliose, laminar, encrusting and columnar) and taxonomic composition (genus level).

Differences in each of the 3 categories sampled at Kolombangara and Vangunu Islands were examined using multivariate procedures (Clarke 1993). Analyses of similarity (ANOSIM) were used to test the null hypothesis that these measures did not differ between treatments or between catchments within each treatment. Similarity of percentages (SIMPER) analyses were used to determine which habitat type, growth morphology and taxa contributed most to the dissimilarity between the two treatments and among areas within each bay adjacent to each catchment.

Differences within each separate component (identified using SIMPER) were examined using a 4-factor analysis of variance (ANOVA). Treatment, Side and Position were fixed and orthogonal factors, while Catchment was a random factor nested within the Logged/Unlogged treatment. Note that for reasons of clarity, the terms Catchment and Bay used here are synonymous. Statistical significance in the ANOVAs was determined with $\alpha = 0.05$ when variances were homogeneous (using Cochran's C Test), but reduced to $\alpha = 0.01$ if transformation failed to stabilise variances (Underwood 1997). If ANOVA detected significant differences, *post-hoc* Student-Newman-Keuls (SNK) tests

were used to identify which means differed within the significant treatment or interaction.

Results

Coral reef habitat

At Kolombangara Island, ANOSIM detected differences in percentage cover of different habitats between unlogged and logged treatments (Global $R = 0.067$, $p = 0.01$) and between catchments within the unlogged (Global $R = 0.301$, $p < 0.001$) and logged treatments (Global $R = 0.272$, $p < 0.001$).

The percentage cover of total dead coral varied

between catchments within each treatment, but the pattern of variation between sides and positions within each bay was not consistent at Kolombangara Island (Table 1, $p < 0.05$). There was more dead coral at the inner position on the southern side of the bay adjacent to Catchment 3, but there were no differences between positions or sides of the bay in the remaining catchments (Fig. 3). The percentage cover of coral rubble varied between sides of the bay, but patterns of variation were not consistent between catchments within each treatment. The percentage cover of sand varied between unlogged and logged catchments, but again, the pattern of variation between sides and positions within each bay was not consistent.

Table 1. Summary of 4-factor ANOVA results. T = Logged/Unlogged treatment, C = Catchment, S = Side (north or south, east or west), P = Position (inner or outer). * $0.05 < p < 0.01$, ** $0.01 < p < 0.001$, *** $p < 0.001$. R = term redundant as there is a significant interaction involving that term.

Variable	Source of Variation										
	T	C(T)	S	P	TxS	TxP	SxC(T)	PxC(T)	SxP	TxSxP	PxSxC(T)
a) Coral habitat											
Kolombangara Is.											
Total dead coral		R	R	R			R				*
Coral rubble		R	R				***				
Sand	R		R	R	R					*	
Vangunu Is.											
Total dead coral	**										
Sand		R	R				*				
Silt		*									
b) Coral morphology											
Kolombangara Is.											
Branching		R	R				*				
Columnar		R	R				*				
Massive		R	R				***				
Vangunu Is.											
Branching		R		R				*			
Columnar	*										
Massive		R	R	R			*	**			
Laminar	R	R	R	R		*	R	R	R		*
c) Coral taxa											
Kolombangara Is.											
Number of genera											***
<i>Montipora</i>	R	R	R	R		*	***				
<i>Favia</i>	*										
<i>Acropora</i>	R	***	R		*						
<i>Porites</i>		R	R				***				
Vangunu Is.											
<i>Montipora</i>		R		R				**			
<i>Porites</i>		R	R	R			R	R	R		*

At Vangunu Island, ANOSIM showed that there were differences in the percentage cover of different habitats between the unlogged and logged treatments (Global $R = 0.254$, $p < 0.001$) and between catchments within the

unlogged (Global $R = 0.346$, $p < 0.001$) and logged treatments (Global $R = 0.261$, $p = 0.001$).

The percentage cover of total dead coral varied between the unlogged and logged catchments at Vangunu

Island (Table 1, $p < 0.01$). Dead coral contributed to over 13% of the habitat adjacent to logged catchments, but less than 1% of the habitat adjacent to unlogged catchments (Fig. 3). The percentage cover of sand varied between unlogged and logged catchments, but trends were not consistent between sides of the bay. The percentage cover of silt varied between bays within logged and unlogged catchments. Percentage cover of silt was greater at logged Catchment 7 than at logged Catchment 8, but there were no differences between the percent cover of silt at unlogged bays.

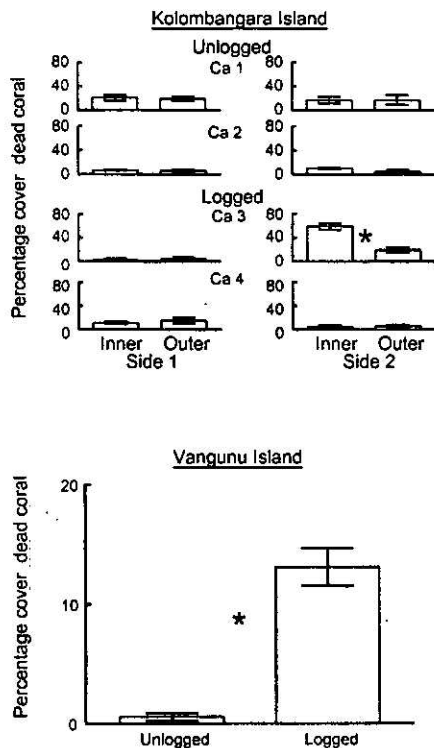


Fig. 3. Mean percentage cover of total dead coral at the inner and outer positions on each side of the bay adjacent to unlogged and logged catchments at Kolombangara Island (top) and at the unlogged and logged catchments at Vangunu Island (bottom). Ca 1 – Ca 4 = Catchments 1 to 4. * = $p < 0.05$.

Coral morphology

At Kolombangara Island, ANOSIM did not detect differences in coral morphology between unlogged and logged treatments, nor between catchments within unlogged treatments. Differences were detected, however, between catchments within the logged treatment (Global $R = 0.274$, $p < 0.001$).

The percentage cover of branching corals varied between the sides of bays, but trends were not consistent between catchments within each treatment at Kolombangara Island (Table 1, $p < 0.05$). The percentage cover of branching coral was greatest at the northern side of Catchment 1 and at the southern side of Catchment 4. No difference in the percentage cover of branching corals was detected between the northern and southern sides of bays at Catchments 2 and 3 (Fig. 4). The percentage cover

of columnar and massive corals varied between sides of bays, but trends were not consistent between catchments within the unlogged and logged treatments.

At Vangunu Island, ANOSIM indicated that differences in coral morphology existed between unlogged and logged treatments (Global $R = 0.1$, $p = 0.002$), and between catchments within unlogged (Global $R = 0.09$, $p = 0.029$) and logged treatments (Global $R = 0.232$, $p = 0.004$).

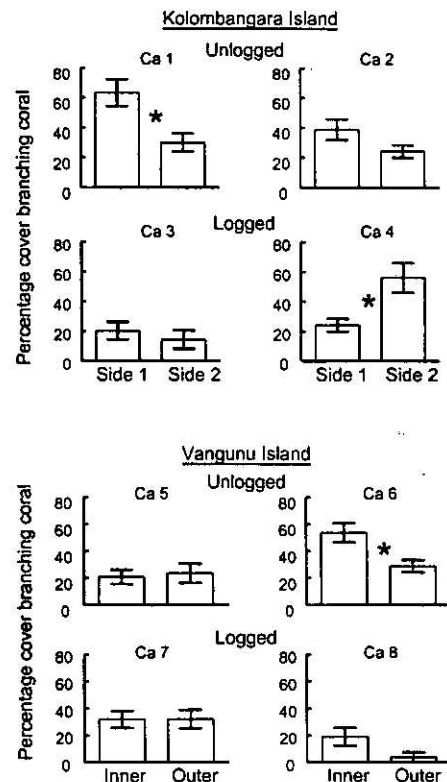


Fig. 4. Mean percentage cover of branching coral on each side of the bay adjacent to unlogged and logged catchments at Kolombangara Island (top) and at the inner and outer positions at Vangunu Island (bottom). Ca 1 – Ca 8 = Catchments 1 to 8. * = $p < 0.05$.

The percentage cover of branching corals varied between the inner and outer positions, but trends were not consistent between catchments within treatments at Vangunu Island (Table 1, $p < 0.05$). There was a greater proportion of branching corals at the inner position at Catchment 6, compared with the outer position. There were no differences between the inner and outer positions at the other catchments (Fig. 4). The percentage cover of columnar corals was greater adjacent to logged catchments than unlogged catchments. The percentage cover of massive corals differed between the northern and southern sides of bays, but patterns of variation were not consistent between catchments within the unlogged and logged treatments. Differences in the percentage cover of massive corals were also detected between the inner and outer positions, but again, trends were not consistent between catchments within each treatment. There was a greater cover of laminar corals at the outer position adjacent to unlogged catchments compared with inner

position, but there was no difference between positions adjacent to logged catchments. The percentage cover of laminar forms also varied between positions and sides, but patterns of variation differed between catchments within treatments.

Assemblage of coral taxa

Coral assemblages differed between unlogged and logged treatments (Global $R = 0.061$, $p = 0.007$) and between catchments within the unlogged (Global $R = 0.189$, $p = 0.002$) and logged treatments (Global $R = 0.211$, $p < 0.001$) at Kolombangara Island.

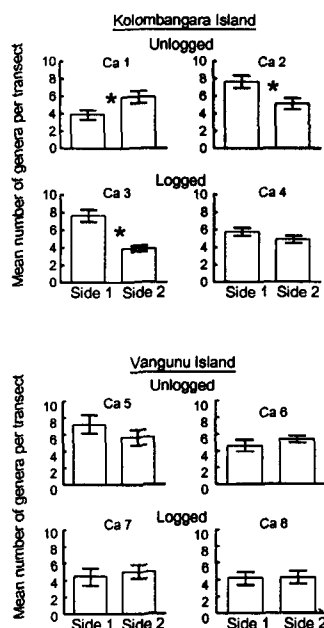


Fig. 5. Mean number of genera per transect on each side of the bay adjacent to unlogged and logged catchments at Kolombangara Island (top) and at Vangunu Island (bottom). Ca 1 – Ca 8 = Catchments 1 to 8. * = $p < 0.05$.

The taxon richness (number of genera) varied inconsistently between sides of bays adjacent to unlogged and logged catchments at Kolombangara Island (Table 1, $p < 0.001$). There were greater numbers of taxa at the northern sides of the bay at Catchments 2 and 3, but more taxa were found at the southern side of Catchment 1. Similar numbers of taxa were observed between the northern and southern sides of the bay at Catchment 4 (Fig. 5). The percentage cover of *Favia* was greatest in bays adjacent to logged than unlogged catchments. The percentage cover of *Montipora* varied between the northern and southern sides of the bays, but trends were not consistent between catchments within each treatment. In addition, the percentage cover of *Montipora* varied between the inner and outer position at the unlogged and logged catchments. There was no difference in the percentage cover of *Montipora* at the inner position between unlogged and logged catchments, but at the outer positions, the percentage cover of *Montipora* was greatest adjacent to unlogged catchments. The percentage cover of *Acropora* differed between sides of bays adjacent to

unlogged and logged catchments and between bays adjacent to unlogged and logged catchments. The percentage cover of *Porites* varied inconsistently between the sides of bays within logged and unlogged catchments.

Differences were detected in the assemblages of corals between unlogged and logged treatments (Global $R = 0.151$, $p < 0.001$) and between catchments within the unlogged (Global $R = 0.295$, $p < 0.001$) and logged treatments (Global $R = 0.102$, $p = 0.041$) at Vangunu Island.

In contrast to the differences detected at Kolombangara Island, taxon richness showed no significant differences between catchments at Vangunu Island (Fig. 5). The percentage cover of *Montipora* and *Porites* varied between the inner and outer positions and between sides of bays, but again, trends were not consistent between catchments.

Discussion

With the exception of the percentage cover of dead coral in bays adjacent to logged catchments at Vangunu Island, few trends were detected during the pilot study that were consistent with an effect of logging. Notwithstanding this, the data collected highlight several important points. First, replication at various spatial scales is vital for the reliable assessment of an impact such as runoff associated with logging. In the absence of replication at several spatial scales, differences due to natural variation between treatments, or bays within treatments, might have been attributed erroneously to an effect of logging. For example, on Kolombangara Island, significant differences in the percentage cover of dead coral between positions on the southern side of the bay at logged Catchment 3 could potentially be attributed to an effect of logging, i.e. there was more dead coral at the inner position on the side of the bay that appeared to receive the greatest amount of runoff. Importantly, however, there were no differences in the percentage cover of dead coral among positions or sides elsewhere in bays adjacent to logged catchments on Kolombangara Island.

Second, multiple control locations are essential in the assessment of environmental impacts. Whilst there were significant differences in the number of genera between sides of the bay adjacent to logged Catchment 3 at Kolombangara Island, there were also significant differences in the number of genera between sides of the bay at the unlogged catchments (i.e. controls). Natural differences at the controls, which were unaffected by logging, invalidate the interpretation that differences were due to an effect of logging because it is not possible to determine whether differences were due to natural variation or logging activities. The sensitivity of the statistical tests used will increase when a temporal component and the third treatment (previously logged) is added to the main study, thus, clearer trends may become apparent as the study progresses.

Ideally, we would have compared two islands of similar geomorphology for each type of logging operation, i.e. coral reefs adjacent to 2 islands where

plantation and virgin logging occurs. Furthermore, if the coastal environment surrounding these islands were similar, then we would have been able to test for differences between the two alternative types of logging operation. Unfortunately, these 'islands' and conditions do not exist. Notwithstanding these limitations, investigating logging effects on separate islands still provides a broader understanding of effects than focusing on a single region. The preliminary data collected suggest that coral communities *differ* in their response to logging given that variation for some variables was not consistent between islands.

Although the hierarchical sampling design is appropriate for assessing the effects of logging on coral reefs, it is not without potential problems. For example, natural variation (or the effects of other human activities) among replicate catchments can affect the power of the design to detect the effects of logging. The use of 'sentinel' species and settlement plates has been proposed for the main study, as an experimental approach, to overcome situations where variation in natural environmental factors between catchments for the same treatment is so great, that it affects the ability of the sampling design to detect any effects due to logging. Ideally, the sentinels would be cultured from the same genetic stock through budding so that genetically identical colonies would be used for field experiments. Preliminary trials have returned encouraging growth rates and low mortality using different sized nubbins of: *Pother cylindrica* (ICLARM, unpublished data). This species would make an ideal sentinel species because it was common to both islands. In a similar way, settlement plates would be used to examine the effects of runoff associated with logging on coral recruitment.

In conclusion, sources of land based pollution have the potential to have significant effects, not only on aquatic habitats and biota, but also on human populations reliant on artisanal fisheries. This study represents an opportunity to quantify the effects of runoff associated with logging using study and reference areas that remain otherwise undisturbed in Solomon Islands. The incorporation of the previously logged treatment into the main study (i.e. those catchments logged within the last 2 — 5 years) is expected to provide information on the nature of recovery of coral reefs from this type of disturbance in the Western Pacific.

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