Determining Effects of an Oil Spill on Fish Communities in a Mangrove - Seagrass Ecosystem in Southern Australia

Rod M. Connolly[1]* and G. Keith Jones[2]

[1]Lecturer in Marine Ecology, Faculty of Environmental Sciences, Griffith University, Qld, 4111, Australia.
[2]Chief Scientist, Fin-fish Fisheries, South Australian Research & Development Institute - Aquatic Sciences, PO Box 120, Henley Beach, SA, 5021, Australia.

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Abstract

Fish associated with mangrove-lined creeks were surveyed using fine-mesh seine nets inside and outside a section of coast contaminated by an oil spill from the *Era* vessel in Spencer Gulf, South Australia, in August 1992. At two sampling periods (3 and 6 months after the spill) fish assemblages at each tidal creek were found to be distinct and assemblages from creek entrances were different to those from within creeks at one period. No differences between assemblages inside and outside the oiled section of the coast could be detected, even though the study design and statistical analyses should have been able to detect any sizeable impact of oil on fish communities. Abundances of economically important species were not consistently different inside and outside the oiled area, although they differed among creeks. Juveniles of several economically important species were significantly smaller in oiled creeks than in unoiled creeks, raising the concern that oil retarded growth rates.

Key Words: Hydrocarbons, fish, community analysis, ANOSIM, *Sillaginodes punctata*

Introduction

The timing and location of oil spills are considered to be critical in determining the effects on the population dynamics of fish (Reed *et al.*, 1984). Fish nursery areas are often characterised by sheltered, low energy coastline and low water circulation. In these areas, oil spills could potentially cause the greatest effects because of the relatively greater vulnerability of eggs, postlarvae and juveniles to oil (Eldridge *et al.*, 1977) when compared with adult fish which have the ability to move away from the spills (Squire, 1992; and see review by GESAMP, 1993).

On 30 August, 1992, part of a known fish nursery area was oiled following a spill resulting from a collision between the oil tanker *Era* and a tug in northern Spencer Gulf, South Australia (Figure 1). Almost 300 tonnes of diesel oil and heavy residual oil were released. Oil came ashore 2 days later along an 8 km stretch of coast supporting mangrove (*Avicennia marina* (Forsk.) Vierh.) forest and seagrass (*Zostera, Heterozostera*) meadows (Wardrop *et al.*, 1993). A number of studies on the effects of the spill were instigated on different components of the ecosystem, including mangroves, seagrasses, invertebrates and fish. Early progress reports describe the death of mangroves in heavily oiled areas (Wardrop *et al.*, 1993; K. Edyvane, unpubl. data), but show that any effect of oil on seagrasses was obscured by more widespread browning and leaf-loss caused by other factors (Connolly, 1994a). The abundances of small, motile invertebrates associated with the seagrasses were affected by the browning and leaf-loss of seagrass but, again, any effect of oil was obscured (Connolly, 1994a).

The waters of northern Spencer Gulf, an inverse estuary on the southern Australian coastline (Nunes and Lennon, 1986), contain important commercial and recreational fin-fish net and line fisheries with a commercial value of $Aus 4.6 million (South Australian Research and Development Institute, unpubl. data). By regulation, the hauling net (small lampara) fishery is confined to a depth limit of 5 metres and occurs generally over seagrass and sand/mud areas, sometimes in close proximity to mangrove forests. Handline and longline fisheries occur in both the shallows and channels (up to 20 m depth) of the gulf (Jones *et al.*, 1990).

Studies in similar habitats in South Australia have highlighted the importance of mangrove/seagrass areas

* Author for correspondence

as nursery, spawning and feeding areas for a number of those fish species taken in the net and line fisheries in northern Spencer Gulf (Jones, 1984; Connolly, 1994b).

This paper reports on a study of the fish communities and growth of juvenile fish in the mangrove/seagrass ecosystem, with the specific aims of determining the effects of the oil spill on:

i) the species composition of assemblages of highly mobile fauna in and adjacent to the creeks,
ii) the relative abundances of economically important species, and
iii) the average sizes of juveniles of economically important species.

It was planned to sample the area twice, with the timing of sampling chosen to coincide with the presence of juveniles of the economically important species, as shown from surveys in similar habitats in other parts of South Australia.

Methods

Sampling

All netting was carried out with the assistance of local commercial net fishers using shallow-draft planing-hull vessels. Sites at the entrances and inside the creeks were sampled, both in unoiled and oiled creeks. Table 1 shows the number of shots, types and areas of shots sampled during November 1992 and February 1993 (hereafter referred to as November and February). Powerhaul shots were used in the wider parts of creeks and at the entrances to creeks. In these shots, nets were set in a half circle and then closed up, under the power of the vessel, whereas ring shooting was undertaken in the narrower parts of the creeks, with the nets shot in a full circle. In both types of shots, the seine nets were hauled onto the sand/mud banks, where sorting and measuring took place. Figure 1 shows the location of the sampling sites at each period of sampling. All shots were undertaken at low tide, when there was relatively little water movement. Entrance sites were seaward of the mangrove forest, with patchy, short eelgrass (*Zostera mucronata* den Hartog) in places, whereas within-creek sites were bounded by the mangrove - samphire habitat but did not support submerged vegetation.

Fish were sampled using a beach seine net of 120 m length, consisting of two wings each 30 m in length with stretched mesh size of 3 cm, and a 10 mm mesh

Table 1. *Number, type and area of net samples in November and February (P = Powerhaul, R = Ring).*

Creek	NOVEMBER						FEBRUARY					
	Entrance			Creek			Entrance			Creek		
	No. shots	Shot type	Total sampling area (m^2)	No. shots	Shot type	Total sampling area (m^2)	No. shots	Shot type	Total sampling area (m^2)	No. shots	Shot type	Total sampling area (m^2)
B (unoiled)	3	P	10 404	2	R, P	4602	3	R,P	8080	2	R,P	4602
C (oiled)							1	P	3468			
D (oiled)	2	P	6936	2	P	6936	2	P	6936	2	P	6936
E (oiled)							2	P	6936	2	P	6936
F (oiled)	2	P	6936	1	R	1134				1	R	1134
H (unoiled)							3	P	10404	2	R,P	4602

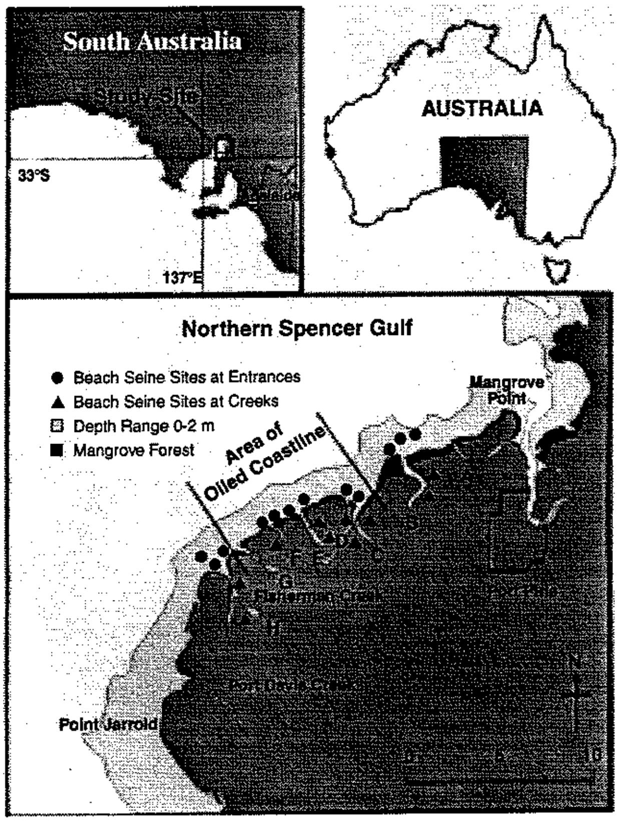

Figure 1. *Location of creeks and sampling sites in northern Spencer Gulf.*

bunt of 60 m length in the centre. The net was weighted along its length at the bottom and polystyrene floats were used along the top. To aid the initial hauling of the net, 20 m lengths of rope were attached to both ends of the net.

Efficiency of the beach seine net was not quantified, and estimated densities are considered to be minima. Densities are useful, however, for comparison from shot to shot. After each shot, all fish caught were transferred immediately to holding cages, identified and counted. Blue swimmer crabs (*Portunus pelagicus*) were also counted, and these numbers are included in analyses of "fish" assemblages. Two hundred randomly selected individuals (or all individuals, if fewer than 200 were caught) of each of the following economically important species were measured (to nearest cm) from each shot: King George whiting (*Sillaginodes punctata*), yellowfin whiting (*Sillago schomburgkii*), yelloweye mullet (*Aldrichetta forsteri*), Australian salmon (*Arripis truttacea*), tommy ruff (*Arripis georgiana*) and sea garfish (*Hyporhamphus melanochir*).

Surface water temperature and salinity were measured at all sites at creek entrances at both periods.

Data analyses

Fish assemblages (all species together) were compared using an analysis of similarities (ANOSIM), which is a non-parametric analogue to a multivariate analysis of variance (MANOVA) without the assumption of multivariate normality (Clarke, 1993). ANOSIM has an additional advantage over MANOVA in being able to detect a difference between groups without any need for assumptions of constant spread within each group (Clarke, 1993). ANOSIM compares ranked similarities between and within groups selected *a priori* (e.g. oiled / non-oiled) using a randomisation test for significance. ANOSIM was used to test for differences between data from oiled and non-oiled creeks, between creek-entrance and within-creek assemblages, and amongst assemblages from individual creeks for data from November and February considered separately, and then for both data sets combined. Differences between dates were also tested. In the analysis of February data, creeks were treated as a nested factor (creeks) within the main factor (oil). This nested ANOSIM tested whether assemblages differed between oiled and non-oiled creeks by separating any differences due to oil from within creek variability (ie. the logic is equivalent to a nested ANOVA). All ANOSIM tests involved 5000 simulations using the PRIMER package from Plymouth Marine Laboratory, UK. No tests were made of differences between the two netting methods, powerhaul and ring shots, because too few ring shots were taken.

The relationships amongst assemblages from each collection are presented graphically using non-metric multi-dimensional scaling (MDS), an ordination procedure that uses the same matrix of ranked similarities as used in ANOSIM. MDS displays samples in low (usually two) dimensional space while retaining as nearly as possible the similarity rankings between samples.

For comparisons of fish assemblages, raw counts were transformed using $x^{0.25}$ to avoid emphasising only the very common species in the analysis. The Bray-Curtis similarity coefficient was used to compare assemblages (Clarke, 1993). ANOSIM tests were repeated on February data with a less severe transformation ($x^{0.5}$) and with no transformation. Probabilities varied slightly but there was no change in the significance of any factor, so these values are not shown.

The relative abundances of economically important species were analysed using several different ANOVA tests. For November data, abundances of economically important species which were caught at enough sites to permit a valid test were compared using one-way ANOVA tests for the factors: oil, creek, entrance/within creek. Abundances were also tested using a two-way ANOVA with oil and entrance/within creek as the two, fixed factors. No nested ANOVA tests were done because there was only one unoiled creek, which would make this test very weak. For February data, the same one-way and two-way ANOVA tests were done as described for November but additionally, abundances were tested with nested ANOVA using oil as the main, fixed factor and creek as the nested, random factor. This test is equivalent to the nested ANOSIM used for multivariate tests; it tests for oil effects using among creek variance as the error term. All tests were done on $\log_{10}(x + 1)$ transformed data after checking using F_{max} test that the transformation increased homoscedasticity. Factorial and nested ANOVA tests are usually preferable to one-way ANOVA tests in that they provide more sensitive tests because they partition variance more fully. In the present case, however, the uneven and low level of replication make results of these more complex ANOVA models less reliable, and we therefore have shown also the results of one-way ANOVA tests. For both periods, individuals of *Arripis georgiana* were caught at few enough sites to make even one-way ANOVA results unreliable and the non-parametric Kruskal Wallis equivalent was used for this species. Significant ANOVA results for the factor Creek were followed by Tukey pairwise comparisons (or the non-parametric equivalent in the case of *A. georgiana*).

Key commercial species showed clear temporal patterns of recruitment to the study site, and these patterns matched the timing of recruitment into other South Australian coastal areas, with *Sillaginodes punctata* and *Aldrichetta forsteri* settling in late winter to spring (July - October) and *Sillago schomburgkii* settling in summer (December - January) (Jones *et al.*, 1990). Mean lengths of the smallest size class were compared at each date. For February data, means were compared using a nested ANOVA with oil as main, fixed factor and creek the nested, random factor. For November data, with only one unoiled creek sampled, the nested ANOVA was considered to lack rigour and instead one-way ANOVA tests were made separately on the factors oil and creek. For both periods, measurements of individuals from all nets within a creek were pooled. Data were homoscedastic (F_{max} test) and in most cases seemed close to having a normal distribution (visual inspection), and data were not transformed.

Results

Species composition of assemblages

November sampling

The ordination plot of all fish assemblages is shown in Figure 2. There appears to be some grouping of oiled/ unoiled assemblages, but at least as obvious is the grouping of individual creeks. Collections from creek entrances and within-creeks were not clearly separate. Given the grouping of individual creeks, differences resulting from oiling could be expected to show as oiled creeks being closer to each other than to the unoiled creek; that is, assemblages from creeks D and F (oiled) should be closer to each other than to assemblages from creek B (unoiled). This is not evident in the ordination plot (Figure 2). ANOSIM results confirmed that differences amongst creeks were significant ($p = 0.043$), although the small number of collections in creeks prevented meaningful pairwise tests of which creeks were more similar to each other. Differences between entrance and within-creek assemblages ($p = 0.234$) and between oiled and unoiled assemblages were not significant ($p = 0.087$). No formal power calculations are currently possible with the ANOSIM method but the small number of replicate shots serves as a reminder that a Type II statistical error is possible.

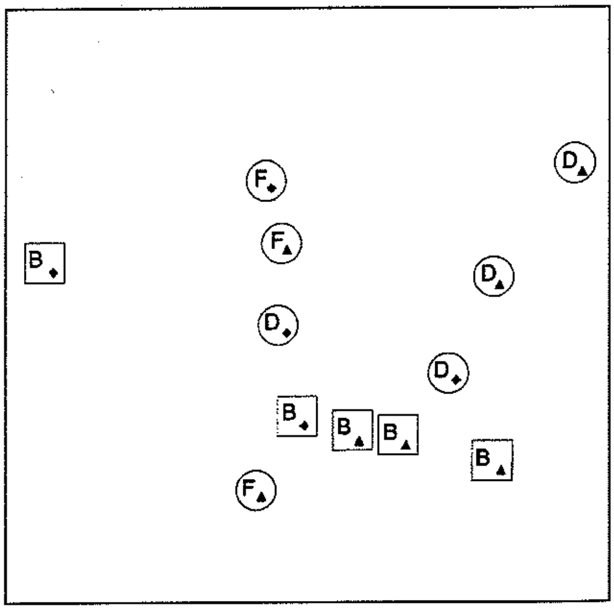

Figure 2. *MDS ordination plot of fish assemblages determined from all shots in November. Stress (Kruskal's formula 1) = 0.118. Plot is labelled as follows: a) Oiled (large circle) v Unoiled (large square) sites, b) by Creek (lettering as in Fig. 1), c) Within Creek (small diamond) v Entrance (small triangle) sites.*

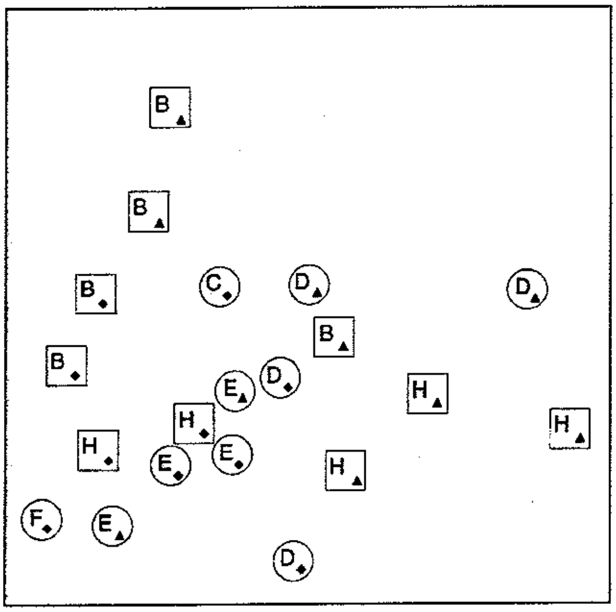

Figure 3: *MDS ordination plot of fish assemblages from all shots in February. Stress = 0.156. Labelling as in Fig. 2.*

February sampling

The ordination plot of all assemblages (Figure 3) showed some grouping of individual creeks and some separation of entrance and within-creek assemblages. No obvious grouping of oiled and unoiled assemblages was evident. Assemblages from creek H (unoiled) overlapped those of creeks D and E (oiled). Of the creeks from which replicate collections were taken, the most obvious separation is that of creek B (unoiled) from all other creeks. A one-way ANOSIM test (Table 2) confirmed that differences among creeks were significant. Pairwise ANOSIM tests were useful for comparing creeks from which replicate collections were taken, and showed that creek B was different from all other creeks. Differences between entrance and within-creek assemblages were significant, but between oiled and unoiled assemblages were not. The nested ANOSIM result (Table 2), after accounting for the strong differences amongst creeks, did not detect a significant difference between oiled and unoiled assemblages.

Assemblages from entrance collections alone (Figure 4) showed some grouping of individual creeks. Oiled and unoiled assemblages were not grouped, and creeks D and E (oiled) were not closer to each other than to creeks B and H (unoiled). A one-way ANOSIM test showed no significant difference between oiled and unoiled assemblages (Table 2). A nested ANOSIM test was not useful because of the small number of creeks within oiled and unoiled habitats. A one-way ANOSIM test did not detect a significant difference amongst creeks (Table 2).

Table 2. *Results of ANOSIM comparisons amongst fish assemblages collected in February.*

Collections used in tests	Factor	Result
All		
	Oil/Non-oil	0.091 ns
	Entrance/Within-creek	0.009
	Individual creeks	0.028
	Pairwise comparisons amongst creeks	B,D; B,E; B,H
	Nested test - Oil/Non-oil	0.467 ns
	- Individual creeks	0.007
Entrance only		
	Oil/Non-oil	0.640 ns
	Individual creeks	0.054 ns
Within-creek only		
	Oil/Non-oil	0.086 ns
	Individual creeks	0.005
	Nested test - Oil/Non-oil	0.600 ns
	- Individual creeks	0.089 ns

All collections used in tests. Results are probabilities. Level of significance = 0.05, and ns = not significant. Pairwise comparisons between individual creeks followed significant overall test amongst creeks; results are creek pairs significantly different at 0.05 level (e.g. B,D means that creeks B and D were significantly different). Pairwise comparisons on entrance and within-creek data separately were not meaningful because of the small number of collections in each creek.

Assemblages from within-creek collections alone (Figure 5) again showed some grouping of individual creeks. Oiled and unoiled assemblages did show some separation, but a one-way ANOSIM test did not indicate a significant difference (Table 2). A nested ANOSIM confirmed that even after differences amongst individual creeks were accounted for, the difference between oiled and unoiled creeks was not significant (Table 2). That is, although creeks B and H were on the same side of the ordination plot, there is a high chance of this happening even if oiling had no effect on fish assemblages. A one-way ANOSIM test showed significant differences amongst creeks (Table 2).

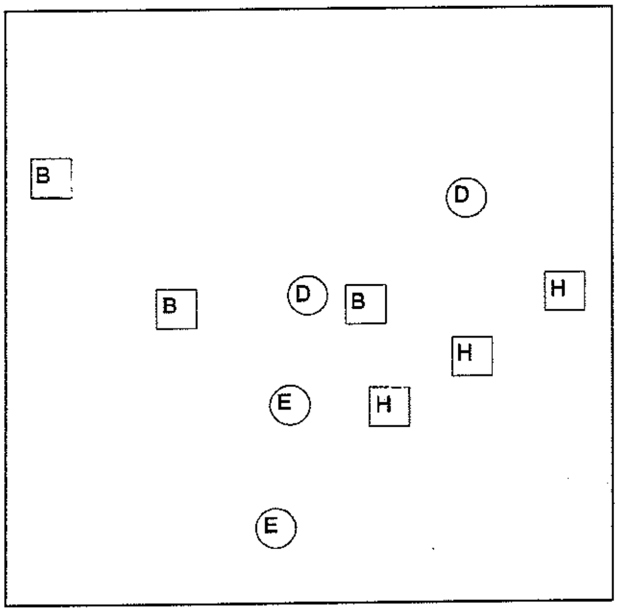

Figure 4: *MDS ordination plot of fish assemblages from entrance shots in February, 1993. Stress = 0.079. Labelling as in Fig. 2.*

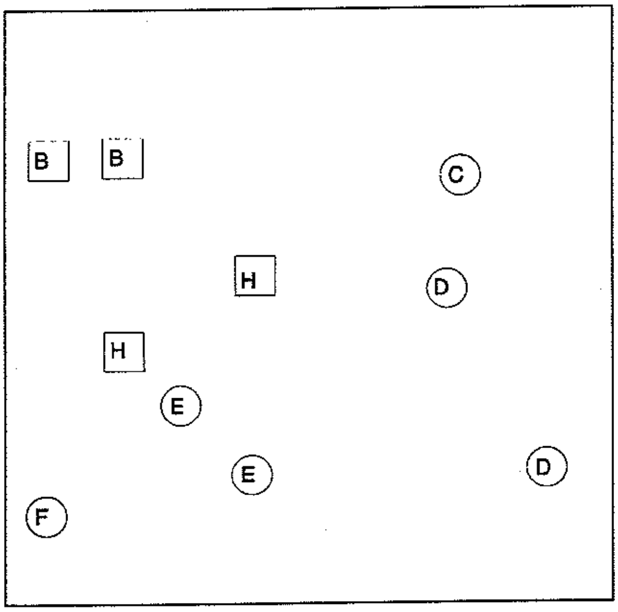

Figure 5: *MDS ordination plot of fish assemblages sampled within the creeks in February. Stress = 0.127. Labelling as in Fig. 2.*

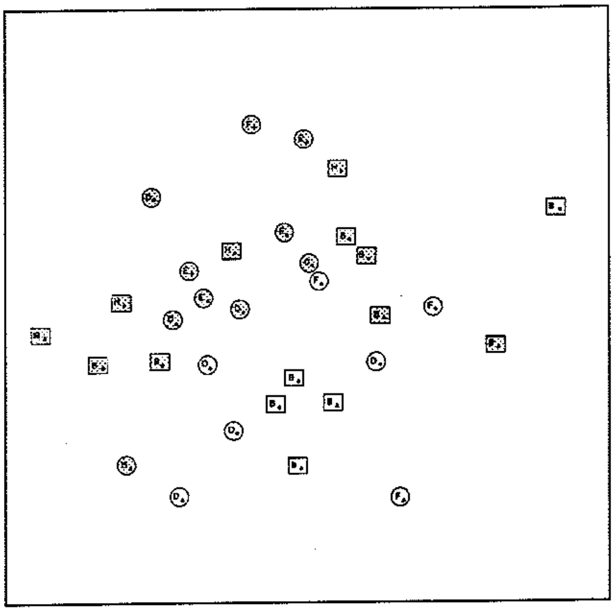

Figure 6: *MDS ordination plots of fish assemblages for both dates combined. All shots. Stress = 0.197. Labelling as in Fig. 2; additionally, November (unshaded) v February (shaded).*

Table 3. *Results of ANOSIM comparisons amongst fish assemblages collected in November and February.*

Factor	Result
Oil/Non-oil	0.282 ns
Entrance/Within-creek	0.056 ns
Individual creeks	0.007
Pairwise comparisons amongst creeks	B,D; B,H
November/February	< 0.001
Nested test - Oil/Non-oil	0.400 ns
- Individual creeks	0.003

Results are probabilities. Level of significance = 0.05, and ns = not significant. Pairwise comparisons between individual creeks followed significant overall test amongst creeks; results are creek pairs significantly different at 0.05 level (e.g. B,D means that creeks B and D were significantly different).

Combined periods

Grouping of individual creeks and separation of entrance and within-creek assemblages was noticeable but not marked in the ordination plot of all assemblages (Figure 6). Oiled and unoiled assemblages were not separate. The most conspicuous grouping was of assemblages from the two sampling periods. One-way ANOSIM tests confirmed that oiled and unoiled assemblages did not differ significantly, but that differences amongst creeks and between the two sampling periods were significant (Table 3). Pairwise comparisons between individual creeks in which

Table 4. *Relative abundances (mean no.fish/100 m²)(s.e.) of commercially important species for November and February.*

Species	NOVEMBER Creek			FEBRUARY Creek					
	B	D	F	B	C	D	E	F	H
Sillaginodes punctata	1.5 (0.5)	1.5 (0.4)	0.8 (0.2)	18.9 (8.0)	0.7	0.8 (0.3)	1.6 (1.0)	3.3	0.9 (0.5)
Sillago schomburgkii	0.9 (0.5)	0.7 (0.4)	0.5 (0.2)	3.2 (2.0)	0.6	0.6 (0.1)	0.4 (0.2)	3.1	0.9 (0.4)
Aldrichetta forsteri	3.3 (1.3)	0.4 (0.3)	0.3 (0.1)	33.6 (32.6)	0.8	0.5 (0.2)	4.6 (2.1)	11.9	2.2 (1.3)
Hyporhamphus melanochir	9.1 (4.7)	0.4 (0.1)	2.4 (1.6)	0.1 (0.1)	0.03	0.8 (0.7)	0	0	0
Portunus pelagicus	24.2 (8.7)	6.6 (1.1)	2.5 (0.8)	5.8 (2.9)	0.7	0.5 (0.1)	1.4 (0.4)	0	1.3 (0.6)
Arripis truttacea	0.03 (0.02)	0.01 (0.01)	0.02 (0.01)	0	0.2	0.02 (0.02)	0	0	0.03 (0.03)
Arripis georgiana	1.5 (1.3)	0.01 (0.01)	0.01 (0.01)	1.4 (1.4)	0.7	0.2 (0.1)	0.01 (0.01)	0	0
All species	46.8 (13.6)	15.9 (5.8)	26.9 (9.6)	96.1 (32.3)	17.0	4.8 (0.7)	17.0 (4.1)	23.9	14.1 (8.4)

multiple collections were taken detected significant differences between creek B and creeks D and H. Differences between entrance and within-creek assemblages were not significant (Table 3). A nested ANOSIM found that after accounting for differences amongst creeks, the difference between oiled and unoiled assemblages was not significant (Table 3).

Relative abundances of economically important species

A total of 12 064 and 15 211 fish were caught during sampling in November and February, respectively. The relative abundances of economically important species are shown in Table 4, and ANOVA results are in Table 5.

In November, *Aldrichetta forsteri* was more abundant in unoiled than oiled areas and abundance in Creek B was higher than in Creeks D and F. *Hyporhamphus melanochir* was more abundant in unoiled than oiled areas in the two-way ANOVA, after accounting for variability due to the entrance/within creek factor. *Arripis georgiana* was more abundant in unoiled than oiled areas. *Portunus pelagicus* and total numbers of fish ("All Species") showed significant interaction between factors oil and entrance/within creek. Abundances were higher in unoiled than oiled areas for entrance sites but were not significantly different for within creek sites.

In February, abundances of *Portunus pelagicus* were significantly higher in unoiled than in oiled areas in the two-way ANOVA. *Arripis georgiana* abundances were significantly higher in Creek B than in all other creeks. This species was not caught at Creeks F and H.

In studies aiming to detect effects of a pollutant it is instructive to make some assessment of the statistical power of tests with non-significant results (Fairweather, 1991). Statistical power, the chance of detecting an effect of a particular magnitude (effect size, or ES), can be calculated using the sample size and the estimate of variability from the ANOVA. In the one-way ANOVA test of the factor oil in February on "All Species" (transformed data), for example, n = 10 and $MS_{error} = 0.378$. Untransformed means were: unoiled, 55.1 fish/100m², oiled, 12.8; that is, oiled areas have 77% fewer fish than unoiled areas. On transformed data, this equates to: unoiled, 1.740, oiled, 1.107. The power of this ANOVA to detect that sized difference was 0.59 (ie. probability of Type II error (ß) = 0.41). Taking this one-way ANOVA as an example, if desirable power was set at 0.80 (ß = 0.2), the detectable ES would have been: untransformed means - unoiled 55.1, oiled 7.9, a reduction of 86%. For power of 0.95 (ß = 0.05), the ES would have been: unoiled 55.1, oiled 4.5, a reduction of 92%.

Size of juveniles of economically important species

A small number of 1992 year class (0 group) *Sillaginodes punctata* were caught in November but there were too few individuals to draw any conclusions. We therefore tested mean lengths of 1⁺ group fish. *S. punctata* (Figure 7) were larger in unoiled than oiled areas (mean 15.3 and 14.7 cm respectively; ANOVA: $p < 0.001$), but also differed significantly among creeks (ANOVA: $p < 0.001$; Tukey: all pairs differ). By February, the 1992 year class dominated catches, and again, mean lengths were significantly greater in unoiled than in

Table 5. *ANOVA results on abundances of key commercial species.*

	One-way ANOVA			Nested ANOVA		Two-way ANOVA		
	Oil	Creek	E/W	Oil	Creek	Oil	E/W	Oil x E/W
NOVEMBER								
Sillaginodes punctata	0.819	0.792	0.145			0.883	0.062	0.055
Sillago schomburgkii	0.767	0.943	0.549			0.939	0.458	0.292
Aldrichetta forsteri	0.002**	0.009**	0.533			0.002**	0.222	0.423
Hyporhamphus melanochir	0.054	0.150	0.486			0.030*	0.095	0.005**
Portunus pelagicus	0.139	0.212	0.439			0.107	0.074	0.003**
Arripis georgiana	0.024*	0.077	0.931			NVT	NVT	NVT
All species	0.097	0.175	0.972			0.115	0.648	0.025*
FEBRUARY								
Sillaginodes punctata	0.186	0.127	0.581	> 0.25	0.122	0.242	0.768	0.888
Sillago schomburgkii	0.285	0.333	0.402	> 0.25	0.333	0.221	0.293	0.963
Aldrichetta forsteri	0.867	0.577	0.390	> 0.25	0.452	0.740	0.389	0.888
Hyporhamphus melanochir	NVT	NVT	NVT	NVT	NVT	NVT	NVT	NVT
Portunus pelagicus	0.059	0.105	0.551	> 0.10	0.215	0.034*	0.266	0.117
Arripis georgiana	0.147	0.049*	0.468	NVT	NVT	NVT	NVT	NVT
All species	0.344	0.072	0.262	> 0.25	0.059	0.212	0.167	0.164

*All values are probabilities. Significant results are marked * < 0.05, ** < 0.001. NVT = No valid test because fish were not caught at enough sites. No tests were possible for Arripis truttacea at either period. Individuals of Arripis georgiana were caught at few enough sites to make ANOVA results unreliable, and Kruskal Wallis probabilities are shown for this species. E/W is comparison between Entrance and Within-Creek samples.*

oiled areas (9.1 and 8.3 cm) after allowing for significant differences among creeks (nested ANOVA: oil, $p < 0.001$; creek, $p < 0.001$).

In November, *Sillago schomburgkii* (Figure 8) in the youngest size class were probably about one year old. Too few individuals of this size class were caught at Creek F to test for differences among creeks, and no significant difference was found between unoiled and oiled areas (13.3 and 13.3 cm; ANOVA: $p = 0.314$).

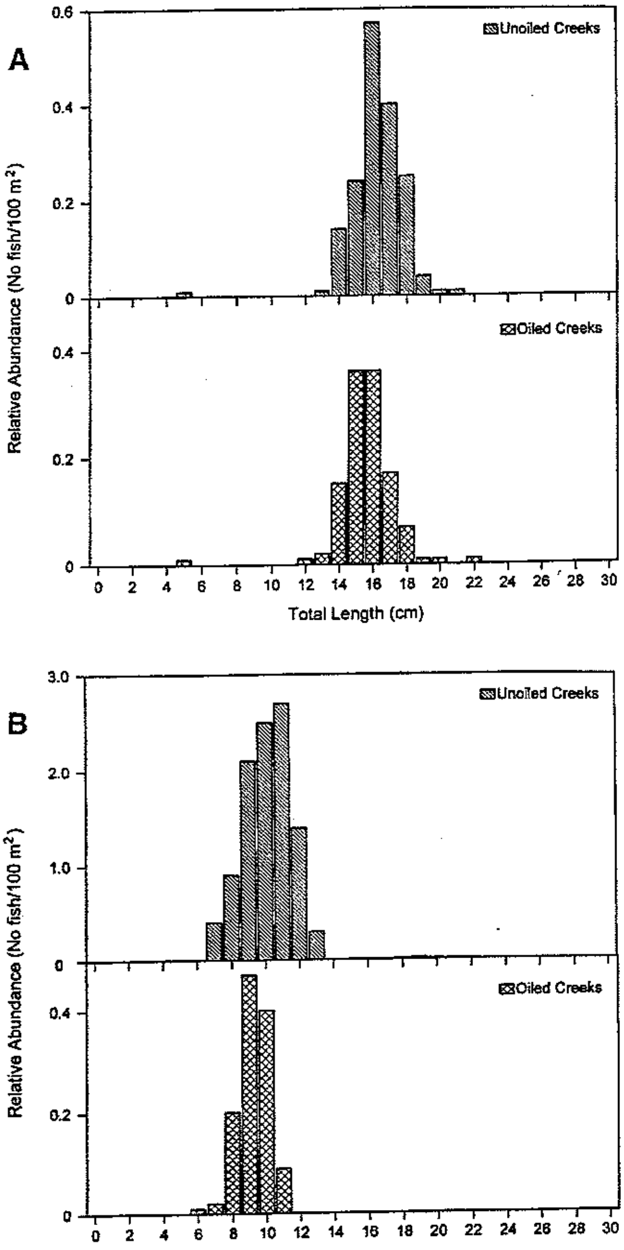

Figure 7: *Size distributions of King George whiting (Sillaginodes punctata) in oiled and unoiled areas for (a) November and (b) February.*

In February, newly arrived recruits were caught in the upper reaches of both unoiled and oiled creeks; fish lengths were not significantly different in unoiled and oiled areas (6.7 and 7.2 cm) after allowing for significant differences among creeks (nested ANOVA: oil, $p > 0.10$; creek, $p < 0.01$). Comparisons among creeks showed that fish from Creek H were smaller than fish from all other creeks.

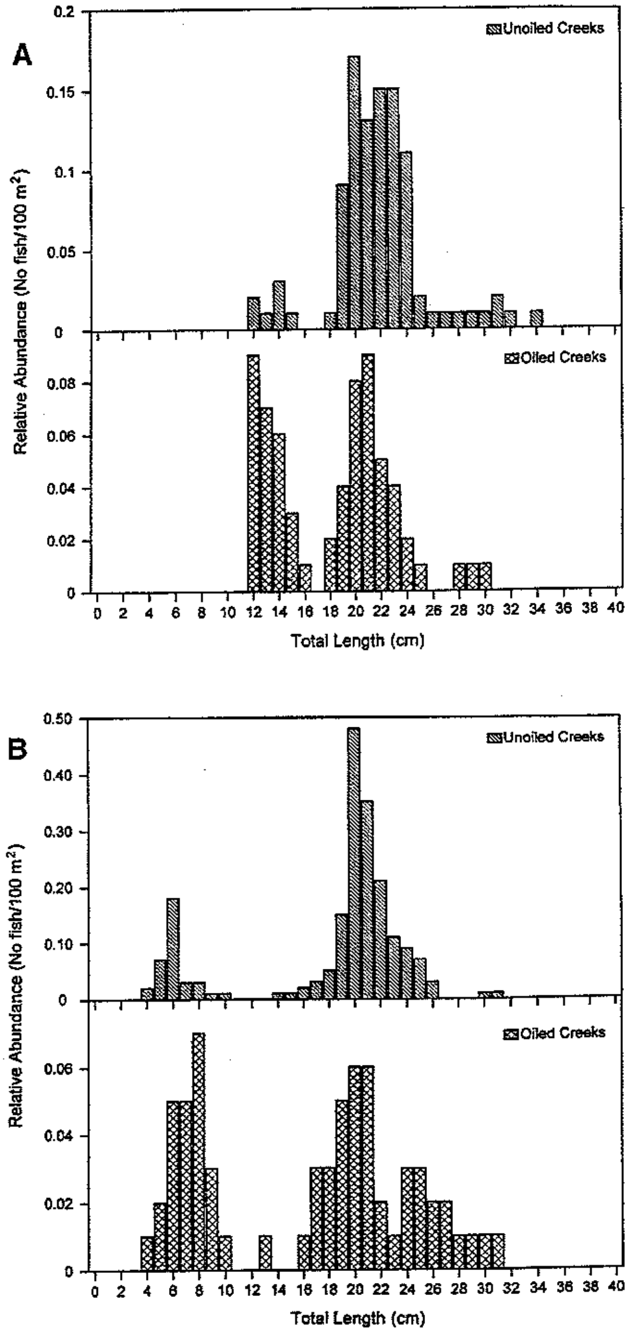

Figure 8: *Size distributions of yellowfin whiting (Sillago schomburgkii) in oiled and unoiled areas for (a) November and (b) February.*

Aldrichetta forsteri (Figure 9) in the 1992 year class were caught in both the November and February sampling periods. In November, no fish of this size class were caught in Creek F, but fish were larger in the unoiled Creek B than in the oiled Creek D (6.9 and 5.5 cm; ANOVA: $p < 0.001$). In February, fish of the smallest size class were larger in unoiled than oiled areas (9.7 and 8.2 cm) after accounting for significant differences among creeks (nested ANOVA: oil, $p < 0.05$; creek, $p < 0.01$). Comparisons among creeks showed that fish from Creek B were larger than from all other creeks.

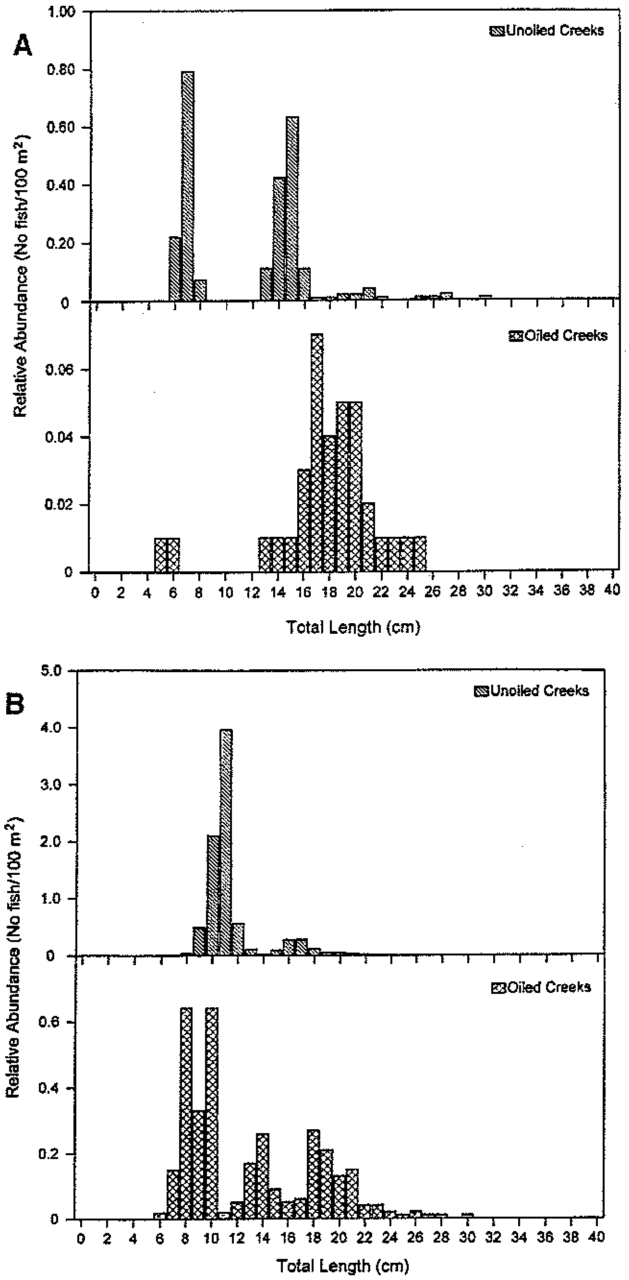

Figure 9: *Size distributions of yelloweye mullet (Aldrichetta forsteri) in oiled and unoiled areas for (a) November and (b) February.*

Table 6. *Mean (s.e.) temperatures and salinities in oiled and unoiled creeks in November and February.*

	Temperature (°C)		Salinity (g/l)	
	November	February	November	February
Unoiled	22.9 (1.3)	25.4 (1.5)	40.41 (0.36)	42.46 (0.16)
Oiled	22.0 (0.6)	24.3 (1.7)	40.62 (0.41)	42.21 (0.35)

The mean lengths of the smallest size class of *Arripis truttacea*, *A. georgiana* and *Hyporhamphus melanochir* were greater in unoiled than oiled areas, although in several cases too few fish were caught in either unoiled or oiled areas to test differences statistically. Where tests were possible, *A. georgiana* individuals were not shown to differ significantly in size between oiled and unoiled areas in February, although they differed among creeks (mean: unoiled, 11.2; oiled, 10.9 cm; nested ANOVA: oil, $p > 0.25$; creek, $p < 0.05$), and *H. melanochir* individuals were significantly larger in unoiled than oiled areas in November (unoiled, 14.6; oiled, 13.3 cm; ANOVA: $p < 0.001$) but were not significantly different in February (unoiled, 16.1; oiled, 15.8 cm; ANOVA: $p = 0.221$).

Environmental data

Average water temperatures were similar in unoiled and oiled areas (too few data, however, to test for statistical significance) at both periods; water was warmer in February than November (Table 6). Salinities were higher in February than November but again were similar in unoiled and oiled areas at both periods (Table 6).

Discussion

The most obvious feature of the fish fauna along the coastline sampled during this study was that fish assemblages at each creek were distinct. This was the consistent finding of the multivariate tests, at both periods and also when periods were pooled. The distinctiveness of assemblages from different creeks suggests that for the detection of effects of oil, replication of sites should be at the level of creek rather than the level of samples within creeks. That is, although enough samples should be taken at each creek to estimate abundances precisely (not always the case in this study), power to detect effects of oil is most sensitive to the number of creeks sampled (Skalski, 1995). The geography of the coastline in the area, however, limits the total number of creeks that could potentially have been sampled.

Although no evidence of an effect of oil on fish assemblages was found, the design and analysis proved to be sensitive enough to detect differences between assemblages from within creeks and from entrances to creeks. As well, the overriding difference shown between assemblages from November and February supports our view that the method of analysis should have been sensitive enough to detect at least major effects of oil, if they occurred.

The chance of detecting more subtle effects of oil would, even in this situation of having a small number of creeks in which to work, be improved by being able to compare assemblages sampled after contamination by oil with those from the same creeks sampled prior to contamination (Green, 1979; Underwood, 1991). Although the epibenthic fauna (including relatively slow-moving fish species) associated with the intertidal and subtidal seagrass beds adjacent to the Pt Pirie creeks were surveyed in a study done > 10 years before present sampling (Ward and Young, 1982), their collection method (beam trawl) does not give a catch comparable with the seine technique. Hauling seines, as used in the present study, are considered much better sampling devices for the schooling species targeted during this survey (Jones *et al.*, 1990).

Any difference between fish assemblages in oiled and unoiled creeks could have gone undetected if the effects of oil were more widespread than originally anticipated, or if large scale environmental changes affected the entire area in a way that obscured effects of oil. Monitoring of intertidal seagrasses until 18 months after the spill along the same stretch of coast showed that large scale browning and leaf loss occurred in oiled areas but also at sites > 100 km north and south of the oiled area (Connolly, 1994a). The conclusion was that any effects of oil would have been obscured by the effects of some other (unspecified) factor (Connolly, 1994a).

The main indication of a possible effect of oil is the smaller size in oiled areas of juveniles of several economically important species. *Sillaginodes punctata* and *Aldrichetta forsteri* were significantly smaller, in the smallest size class, in oiled areas at both sampling periods. *Hyporhamphus melanochir* was smaller in oiled areas in November. The smaller size within oiled creeks of juveniles of several species may have been the result of oil retarding growth. Laboratory studies on striped bass suggest that hydrocarbons can adversely affect feeding behaviour and thus growth rate (Korn *et al.*, 1976). The explanation that oil affected the growth rates in the present study requires the assumption that fish do not move freely between creeks inside and outside the oiled section of coast. We have no direct evidence for lack of movement (such as mark-recapture data) between creeks. The distinctiveness of fish assemblages associated with creeks demonstrated using multivariate analyses, however, suggests that fish do not mix freely amongst creeks. Slower growth rates of fish in nursery areas may influence population dynamics. In a similar mangrove - seagrass ecosystem to that in the present study, for example, individual *S. punctata* having a slower growth rate remained in nursery areas longer than individuals having a faster growth rate (G.K. Jones, unpubl. data). Delayed recruitment to offshore spawning areas may adversely affect the spawning potential of the particular individuals.

The lack of information about fish community structure in the region prior to the spill prevents us from distinguishing between effects of oil on fish abundances and growth rates and ecological factors unassociated with oil such as patterns of recruitment and food availability. Experiments in shallow eelgrass beds have demonstrated, for example, the patchiness of larval supply to different beds within even a small part of a bay (for *Sillaginodes punctata*, Jenkins and May, 1994; for review of other species, Bell and Pollard, 1989). The most recent experiments in southern Australian waters, in particular on *S. punctata*, provide evidence of the importance of interaction between larval supply and food availability (Connolly, 1994c,d; 1995; Jenkins *et al.*, in press). There would be more chance of separating effects of oil from other factors where an oil spill occurred in a water body having a history of surveys and experiments on juvenile fish.

Accidental spills are not experiments; assessment of damage is always hampered by the lack of replication and random assignment of sites to control and treatment (oiled). The difficulties in demonstrating statistically the ecological effects of oil spilled from the *Exxon Valdez* led Skalski (1995) to offer three alternatives to the classic control versus impact analysis used in the present study.

First, rather than comparing control and impact sites, sampling can be aimed at detecting trends with distance from the oiled area. This can give information about more subtle effects but the different sampling strategy does not permit powerful tests of control and impact areas, which may be required by law. Aiming for both trend analysis and comparison of control and impact sites requires greater sampling effort (Skalski, 1995).

Second, monitoring of control and impact areas should be continued long enough to be able to identify any patterns of recovery from differences between control and impact noted soon after the spill. In our case, resources even for the two sampling periods were restrictive to the point of limiting proper replication at some creeks. Other studies within the overall assessment of ecological effects of the *Era* spill, perhaps because they require fewer resources per sampling period, are continuing, and will have a chance of describing any recovery over time.

Third, results of bioassay toxicity tests can be used to predict likely ecological effects. Dose-response relationships are only useful when combined with surveys of concentrations of the contaminant following the spill (Skalski, 1995). No surveys of hydrocarbon concentrations in seawater were undertaken after the *Era* spill, and concentrations in sediment were first measured three months after the spill and again 18 months after the spill. The lack of information about the fate of the pollutant in the weeks immediately following the spill limited the potential for detailed correlations between degree of contamination and ecological effects in all parts of the overall study (Wardrop *et al.*, 1993).

The supervisory body eventually (*after* the spill) given the responsibility of overseeing the ecological monitoring of effects of the *Era* spill (Marine Environment Protection Committee of the South Australian Environment Protection Council) argued that the failure to measure hydrocarbon concentrations after the spill was due to the lack of guidelines for post-spill scientific monitoring (Butler, 1995). They compare this with the rigorous contingency plan guiding the responses of those responsible for the containment and clean-up operations immediately after the spill. The MEPC have also argued that the lack of guidelines led to problems integrating the various government, university and private groups involved in monitoring ecological effects (Butler, 1995).

Conclusions

The sampling design and statistical analyses were capable of separating fish assemblages from different creeks, from within and outside creeks, and between the two sampling periods; the study should therefore have been able to detect, at least, effects of oil as large as these other differences. No effect of oil on the structure of fish communities was demonstrated, although the possibility has been raised that oil may have retarded growth of economically important fish species.

The study demonstrates some difficulties in using fish community structure to determine effects of oil spills. While fish assemblages are an obvious component of the mangrove - seagrass ecosystem to sample because of their economic importance, the evidence should be used in conjunction with results of studies on other components.

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