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[Article]

A Modified Drop Net for Sampling Fish Communities in Complex Habitats: A Description and Comparison with Other Techniques

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Abstract.—A modified drop net (area = 19.3 m^2) was constructed to enhance the collection of fish from within complex freshwater habitats. The net was evaluated in three pools located within the Pilbara region of north Western Australia. The net's efficiency was determined by comparison with gillnetting and beach seining; accuracy of the net was investigated using the toxicant rotenone. In terms of efficiency, the modified drop net and beach seine generated similar descriptions of the fish community (relative abundance, species richness, ordination of a species–abundance matrix); panel gill nets collected a diminished subset of the community. Efficiency of the drop net remained relatively constant among pools, whereas the seine became increasingly easy to use as habitat complexity decreased. In terms of accuracy, the drop net produced estimates of total fish abundance similar to those obtained by use of rotenone and adequately depicted site-related differences in fish community structure (multivariate ordination in space). The drop net and rotenone collected similar numbers of species, but the drop net missed some species that were present in very low abundance. The drop net also underestimated the abundance of one benthic species. We recommend use of the drop net when studying ephemeral pools where habitat complexity changes through time or when precise estimates of density are required. Beach seining, which has minimal gear requirements, is recommended for situations in which only a general description of the community (species–abundance matrix) or species richness information is required. When the drop net is used, gill nets should also be used to collect large size-classes that are in low abundance.

Rocks, dense aquatic vegetation, and deep water make it difficult to collect fish using standard techniques, such as seine nets and electrofishers (Dewey et al. 1989; Perrow et al. 1996; Vaux et al. 2000). Gill nets can overcome these difficulties to varying extents, but they are known to bias against certain fish sizes and movement patterns (Casselman et al. 1990; Knight and Bain 1996). Two techniques that attempt to overcome the aforementioned limitations include pop nets and drop nets. Pop nets sit on the substrate and rise to the surface (Larson et al. 1986; Dewey et al. 1989), whereas drop nets are held at the water's surface and drop to the substrate (Hellier 1958; Kushlan 1974; Lorenz et al. 1997). Pop nets alter the benthic habitat (although less so when floorless) and may be unsuitable for sampling benthic species. Because they lack bottoms, drop nets avoid the problem of benthic habitat alteration; trapped fish are collected using differing methods (Gilmore et al. 1978; Chick et al. 1992; Lorenz et al. 1997). If the method of collection is adequate, then these nets provide a good description of the community (Freeman et al. 1984). An important advantage of using a drop or pop net is that the net encloses a known area, providing an estimate of fish density.

In the freshwater environment, the most widely documented drop nets (and an adapted version, drop traps) are those based on a design by Kushlan (1974). These nets are portable, but most of them are small in area (1 m^2) and shallow in depth (Freeman et al. 1984; Jacobsen and Kushlan 1987; Chick et al. 1992; Trexler et al. 2000). These drop nets cannot sample deepwater habitats, and their small area may reduce their capacity to collect large fish (Jacobsen and Kushlan 1987). Drop nets that target deepwater habitats have been developed (see Bobsien and Brendelberger 2006), as have nets that sample larger areas (see Hellier 1958; Gilmore et al. 1978; Lorenz et al. 1997). However, relatively few nets are concurrently large, deep, and mobile. Moseley and Copeland (1969) developed one such net to sample fish and macrocrustaceans in estuaries (see Kjelson and Johnson [1974] for an adapted version). Their net (area

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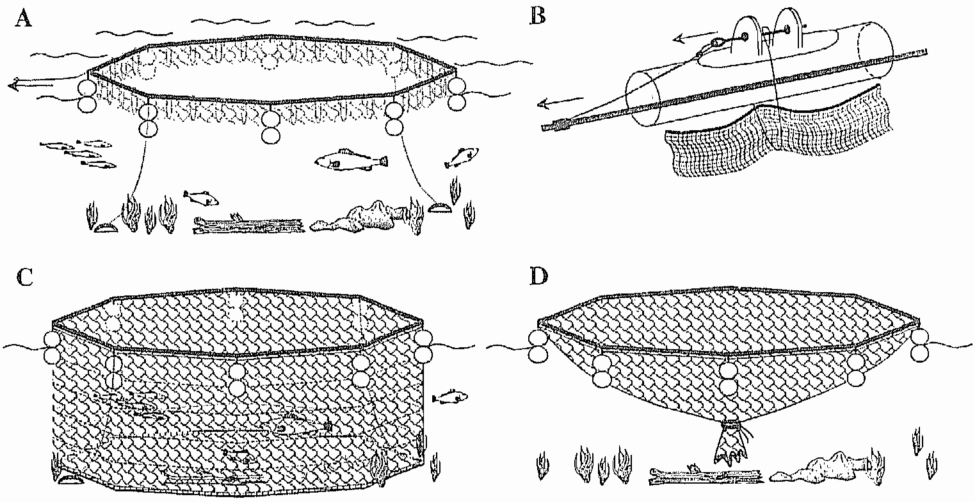

FIGURE 1.—Diagram of a modified drop net and deployment: (A) drop net prior to activation, (B) curtain of netting, held in place prior to release (trace wire encircles the mesh and is held to the frame by a pin; during net release, the pin is pulled by a piece of trace wire that runs around the net's frame [see A]), (C) released net, and (D) gathered net.

= 16 m^2; drop = 5 m) was attached to a frame that floated on the surface of the water and was dropped to the substrate using the weight of a chain that was attached to the skirting of the net. A pursing mechanism at the base of the net was used to trap the nekton. However, this method of closure is unlikely to work over a substrate of thick weeds, rocks, and wood.

To overcome problems associated with the closure of a drop net in complex habitats, a modified drop net was created. The aim of the study was to quantify the efficiency and accuracy of the modified drop net. Efficiency was gauged by comparison with other fish sampling techniques (gillnetting and beach seining). Accuracy was determined by comparison of the drop net with the fish toxicant, rotenone. It was hypothesized that the drop net would be more efficient than beach seines or gill nets and would have a high degree of accuracy. The study was carried out in three riverine pools situated in the arid Pilbara region (Indian Ocean drainage division) of north Western Australia.

Methods

Drop net description and operation.—The mobile drop net consists of three main components: a rigid aluminum frame, a detachable cylindrical net, and a pulley system (Figure 1). The octagonal aluminum frame has 2-m-long sides made of 25-mm-diameter piping with a 1.6-mm wall thickness. The sides of the frame are joined using T-pieces and enclose an area of 19.3 m^2. The T-piece joins have 33-cm-long horizontal arms (32-mm diameter) and a vertical arm that is 25 cm long (25-mm diameter). Both types of arm have a 1.6-mm wall thickness. To reduce rotation of the sides within each join, a circular piece of elastic cord is looped around the shoulder of the T-piece and looped over a reinforced plastic fastening lug that is fixed to the dorsal portion of the adjoining 2-m-long side piece.

Two buoys (15-cm diameter) are attached to the vertical arm of each T-piece join to provide positive buoyancy. The net (2 mm) has a fall of 4.5 m and is attached to the inside of the frame using clips of polyvinyl chloride piping. The base of the net is reinforced by gluing robust fabric to the skirting (60 cm deep). An 8-mm-thick chain is attached to the reinforced skirting of the net by a roll-up pocket that closes using Velcro. The net (with chain) is gathered to the frame and held in place using pieces of trace wire (1.5-mm diameter) that are attached to the frame. Each trace wire (4 wires/side) circles the gathered net and is held to the frame using a pin. The pin joins the loop in the free end of the piece of trace wire to a horizontal double stay-put fastener that has been riveted onto the frame (Figure 1B). Two lengths of trace run in opposite directions away from one corner of the frame, linking pins and meeting to join a 30-m rope that acts as a remote trigger. A sharp tug on the trigger pulls the pins and thereby releases the pieces of trace wire, allowing the chain to drop the curtain of mesh to the riverbed (Figure 1A, C). The chain is flexible enough to adjust to the contours of the riverbed.

The drop net is best assembled in shallow (knee-deep) water. Prior to activation, the net was positioned using two anchors (dive weights) that were attached by rope to the frame; the net was set for 0.5 h. Field observations indicated that in the target pools, 0.5 h was sufficient for fish to resume normal activity. Once the net was activated, a diver using scuba swam the

TABLE 1.—Physical habitat variables describing three riverine pools (Pilbara region, Western Australia) used to compare fish community attributes between dropnetting, gillnetting, beach seining, and rotenone application. Surface area was estimated by measuring pool width in four locations and multiplying the average width by pool length. Depth was averaged from measurements taken every 3 m on four transects situated along the width of the pool. Visibility and habitat complexity (categorical data) were assessed visually. Macrophyte cover (%) was also visually estimated.

Variable	Pool A	Pool B	Pool C
Surface area (m^2)	315	522	675
Maximum depth (m)	1.3	1.5	1.5
Average depth (m)	0.9	0.7	0.5
Visibility	Good	Poor	Nil
Macrophyte cover (%)	80–90	<10	<5
Substrate	Rocks and cobbles	Bedrock and gravel	Rocks and mud
Level of habitat complexity	High	Moderate to low	Low

circumference of the net, pushing the chained skirting towards the center. The skirting was quickly lifted over rocks and logs, while fish were scared inwards away from the curtain edge. After several circumnavigations, the chain was bunched in the center (Figure 1D). A cord was tied around the net, just above the chain, trapping all fish. The anchors and chain were lifted, and the net was moved into the shallow water. Two people then stood inside the net and slowly pulled it above the surface to shepherd the trapped fish into one area. Fish were collected with a dip net. Successive dip-net passes were made until three consecutive passes failed to find fish.

The drop net was relatively inexpensive to construct. The frame and accessories of the net cost approximately US$400 and was made of readily accessible materials. The mesh of the net is likely to be the most expensive part; in this study, the net mesh was donated (D. Dianich, Bay Recreation Inc., Royal Oak, Maryland). With mesh included, the approximate total cost of the drop net is $650; however, cost will be lower if larger mesh is used.

Study area.—The Pilbara region is classified as semiarid, and most rainfall occurs as a result of tropical thunderstorms or cyclonic activity during the summer months. This type of rainfall is unpredictable and hypervariable; as a result, streamflow does not occur every year. During dry periods, rivers exist as a series of ephemeral pools. To minimize the impact of this study on local fish populations, three pools that had a high chance of drying prior to the summer rains were used. While all three pools were relatively small and shallow, they differed considerably in other physical aspects, incorporating many of the variations found in the region (Table 1). Two pools were located within the Fortescue River catchment (pool A: 21°17′46″S, 116°08′29″E; pool C: 21°43′46″S, 117°45′49″E), and the other pool was situated within the Harding River catchment (pool B: 21°19′33″S, 117°04′42″E).

Sampling procedure.—Sampling was conducted in August 2002. At each pool, the same sampling effort (3 h) was used for all techniques except rotenone treatment. Effort included setting the device, using it, and collecting all captured fish. The time required by each technique determined the number of applications. Each drop-net application took 1 h; hence, the drop net was deployed three times at each site. Application of two monofilament panel gill nets (each with four 3-m panels and a depth of 1.3 m) took 1.5 h (set duration = 1.0 h), and therefore the gill nets were deployed twice at each site. One gill net contained larger mesh sizes (50.8, 60.3, 76.2, and 101.6 mm) and was set in the deepwater section of the study pool. The other gill net contained smaller mesh sizes (12.7, 19.0, 25.4, and 28.6 mm) and was set within the shallow section. Gill nets were set perpendicular to the bank. The beach seine was deployed in various sections of the pool for a total of three 1-h bouts. The wings of the seine were 25 m long and 2 m deep and were made of 28.4-mm mesh; the center panel was 5 m long and made of 3.2-mm mesh. Two people deployed the seine. One person stayed close to the bank, holding the far side of the fine-mesh center panel; the other person held the end of the other wing, walked out into the pool (perpendicular to the bank), and circled back towards the bank. The wing mesh was gathered in as the operator approached the bank and fish were trapped in the fine-mesh section. The lead line was kept as close to the substrate as possible.

The location of sampling (for each technique) within a pool was organized so that habitats were sampled in proportion to their relative abundance. Sampling took place between 0800 and 1700 hours, and the application of each technique was randomized. After each sampling period, fish were identified, measured (fork length, cm), and returned to the pool. The pool was then left for 0.5 h before commencement of the next sampling event. Once sampling was complete, rotenone was added to the pool to assess the accuracy

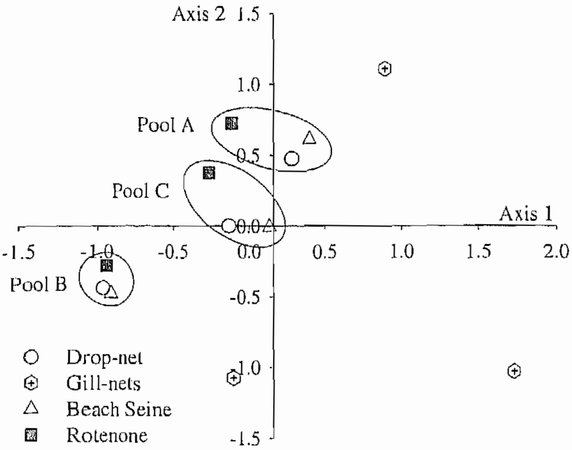

FIGURE 2.—Two-dimensional ordination of fish species versus abundance data collected by dropnetting, gillnetting, and beach seining (standard effort duration = 3 h) at three riverine pools in the Pilbara region of Western Australia during 2002. Collections made after the addition of rotenone are also depicted. Stress associated with the ordination was 0.13 (an acceptable level; Belbin 1992). Pool groupings for all methods other than gill nets are shown within the ovals.

of the different methods (Hockin et al. 1985; Jacobsen and Kushlan 1987). The rotenone was dissolved in a solution of soapy water, and enough solution was dispensed around the pool to create an approximate concentration of 1–2 mg of rotenone/L of water (Davies and Shelton 1983). Affected fish were collected over the next 24 h. Snorkeling was used in deepwater sections to collect fish that had sunk.

Statistical analyses.—A suite of community descriptors was used to assess the efficiency and accuracy of the various techniques. Descriptors included species richness (number of species caught), abundance (total number of individuals caught), size selectivity (size-frequency distribution), and multivariate ordination of a species–abundance matrix (graphical description of community differences in n-dimensional space).

Species richness and abundance were compared among techniques (dropnetting, gillnetting, and beach seining) using a one-way analysis of variance with sites as replicates. Differences between group means were investigated using Tukey–Kramer honestly significant difference (HSD) tests (test statistic, q^*) with a combined significance level (α) of 0.05. Prior to analyses, the data within each group were tested for conformance to parametric assumptions of normality and homogeneity of variance (Zar 1999). Abundance data were $\log_{10}(x + 1)$ transformed prior to analyses. The size selectivity of the various methods was examined using Kolmogorov–Smirnov two-sample tests (Siegel and Castellan 1988). Two-sided paired t-tests were used to examine the accuracy of the fish assemblage (species richness and $\log_{10}[x + 1]$ transformed total abundance) collected by the drop net in relation to the assemblage collected by use of rotenone. To obtain estimates of total abundance, the number of fish collected during 3 h of effort (three applications of the drop net) was multiplied by total pool surface area divided by area sampled (19.3 m^2 × 3 applications = 57.9 m^2 sampled).

The multivariate ordination was performed on $\log_{10}(x + 1)$ transformed abundance data and used dissimilarity measures (association measures) based on the Bray–Curtis coefficient. Ordination of the dissimilarity matrix was achieved using semistrong hybrid multidimensional scaling. The stress involved in the ordination was assessed, and stress values below 2.0 were considered acceptable. If the stress associated with a three-dimensional ordination was less than 0.05, a two-dimensional ordination was used because it is easier to interpret (Belbin 1992). The ordination was conducted using the Pattern Analysis Package (Belbin 1992). Ordination is affected by rare species—those occurring at less than 10% of technique–site replicates (Belbin 1992). In the present study, only one species (Indonesian shortfin eel *Anguilla bicolor bicolor*) was rare and was masked during the analysis.

Results

During the study, 8,021 fish from 12 species were captured: 990 fish were caught in the drop net, 998 were captured by beach seine, 42 were captured in gill nets, and 5,991 were caught by use of rotenone.

Efficiency

For the same 3-h effort, the drop net and beach seine generated similar fish community descriptions, which were quite different from the description generated by gill nets. This difference was most clear when the community was viewed holistically (i.e., ordination of species versus abundance; Figure 2) but was also apparent when fish community attributes (relative abundance, species richness, and size-frequency distribution) were examined.

Before the remaining results are reported, the differences in habitat complexity and community composition among the study sites should be noted (Tables 1, 2). This study was not designed to examine the effect of community composition or habitat-related differences on the efficiency of the techniques, and a statistical evaluation of such effects was not possible; however, it is apparent that site-related trends did exist.

In terms of relative abundance, the drop net and beach seine collected similar numbers of individuals, and each collected significantly more fish than did gill

TABLE 2.—Number of collected individuals of each fish species, total number of individuals collected, and total number of fish species collected by use of a drop net, two gill nets, a beach seine, or rotenone application in three riverine pools of the Pilbara region, Western Australia during 2002 (standard effort duration = 3 h for all methods except rotenone). Asterisks indicate estuarine species.

Fish species or fish community attribute	Pool A				Pool B				Pool C			
	Drop-net	Gill-nets	Seine	Rotenone	Drop-net	Gill-nets	Seine	Rotenone	Drop-net	Gill-nets	Seine	Rotenone
Barred grunter *Amniataba percoides*	10	9	9	25	0	0	0	0	57	0	32	460
Indonesian shortfin eel *Anguilla bicolor bicolor*	0	0	0	5	0	0	0	0	0	0	0	0
Flathead goby *Glossogobius giurus*	20	0	17	388	0	0	0	0	1	0	1	34
Empire gudgeon *Hypseleotris compressa*	187	0	74	107	0	0	0	0	0	0	0	0
Spangled perch *Leiopotherapon unicolor*	4	0	2	44	182	0	160	988	15	1	18	733
Fortescue grunter *L. aheneus*	13	12	4	112	0	0	0	0	0	0	2	26
Indo-Pacific tarpon *Megalops cyprinoides**	2	3	2	4	0	0	0	0	0	0	0	0
Western rainbowfish *Melanotaenia australis*	409	0	173	545	0	0	0	0	9	0	176	411
Striped mullet *Mugil cephalus**	0	4	2	9	0	0	0	0	0	0	0	0
Bony bream *Nematalosa erebi*	0	0	0	0	0	0	0	0	74	13	322	1,260
Hyrtl's tandan *Neosilurus hyrtlii*	3	0	1	111	0	0	0	0	4	0	2	726
Silver scat *Selenotoca multifasciata**	0	0	1	3	0	0	0	0	0	0	0	0
Total abundance	648	28	285	1,353	182	0	160	988	160	14	553	3,650
Total number of species	8	4	10	11	1	0	1	1	6	2	7	7

nets (Table 3; Tukey–Kramer HSD: drop net versus gill nets $q^* = 0.266$, seine versus gill nets $q^* = 0.308$, drop net versus seine $q^* = -1.239$; a positive q^*-value indicates a significant difference at a combined $\alpha = 0.05$). One notable site-related trend was that the drop net caught more than twice the number of fish caught by the seine in pool A, which had the highest level of habitat complexity; however, the seine caught over three times more fish than did the drop net in pool C, which had the lowest level of habitat complexity (Figure 3A; Table 1). The drop net and seine caught similar numbers of fish at pool B (Figure 3A), which had intermediate complexity (Table 1). Differences in the fish community occurred among the sites but cannot account wholly for the result, as the trend in abundance was observed for species that occurred at both sites A and C (e.g., western rainbowfish; Table 2).

In terms of species richness, the drop net, beach seine, and panel gill nets did not differ significantly in the number of species caught (Table 4). Site-related differences were striking. At pools A and C, the drop net and seine caught more species than did the panel gill nets (Figure 3B). At pools A and C, gill nets did not catch small individuals of pelagic species (e.g., western rainbowfish and empire gudgeon) or fish of certain benthic species (flathead goby and Hyrtl's

TABLE 3.—Results of one-way analysis of variance comparing $\log_{10}(x + 1)$ transformed abundance of fish collected by use of a drop net, two gill nets, or a beach seine in three riverine pools (replicates) of the Pilbara region, Western Australia (standard effort duration = 3 h for all three techniques; SS = sum of squares; MS = mean square; $^*P < 0.05$).

Source	SS	df	MS	*F*	*P*
Fishing technique	4.923	2	2.462	9.411	0.014*
Error	1.569	6	0.261		
Total	6.493	8			

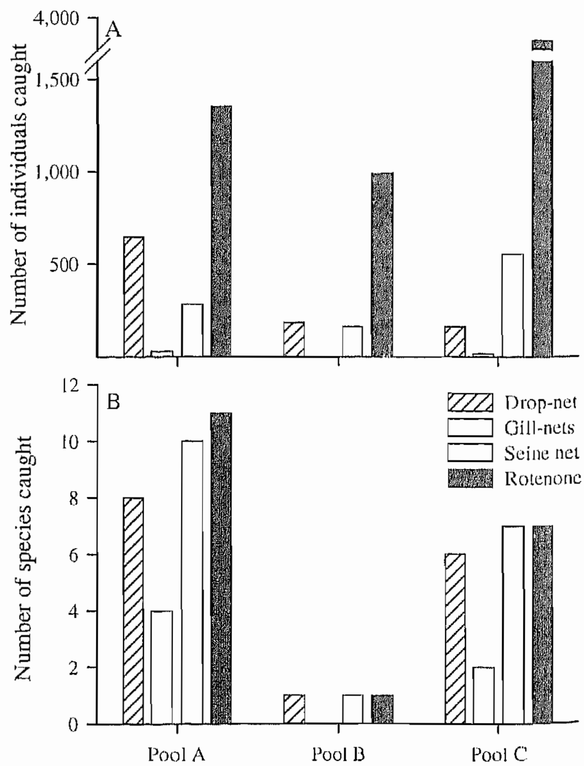

FIGURE 3.—(A) Number of individual fish and (B) number of fish species caught by use of dropnetting, gillnetting, and beach seining (standard effort duration = 3 h) at three pools in the Pilbara region of Western Australia during 2002. Collections made after the addition of rotenone are also depicted.

TABLE 4.—Results of one-way analysis of variance comparing the number of fish species collected by use of a drop net, two gill nets, or a beach seine in three riverine pools (replicates) of the Pilbara region, Western Australia (standard effort duration = 3 h for each technique; SS = sum of squares; MS = mean square; $\alpha = 0.05$).

Source	SS	df	MS	F	P
Fishing technique	26.000	2	13.000	1.026	0.414
Error	76.000	6	12.667		
Total	102.000	8			

tandan; Table 2). There was little difference in species richness among techniques at pool B, which contained only one species (spangled perch; Figure 3B; Table 2).

Size-frequency distributions of captured fish generally differed among techniques (Table 5; Figure 4). The gill nets caught only medium to large size-classes (Figure 4). Distributions in the drop net and beach seine catch varied with site. The drop net caught a greater number of small fish than did the beach seine in the complex environs of pool A, whereas the seine caught a greater number of small fish than did the drop net in the relatively simple habitat of pool C (Figure 4). In pool B, where only one benthic species (spangled perch) occurred and where the habitat was intermediate in complexity, the two techniques collected similar size-frequency distributions (Table 5; Figure 4).

Accuracy

Application of rotenone resulted in the capture of 5,991 fish, approximately three times more fish than were captured by the other three methods combined. However, rotenone was not a completely unbiased estimator. Bias was caused by difficulties associated with the collection of affected fish rather than by the inadequacy of toxic effects, as all species except empire gudgeon were readily disabled by the toxicant. The collection of fish at pool A was hampered by the dense weeds that, although ensuring good visibility, made it very difficult to find fish, particularly the small size-classes. The collection of fish at pools B and C was severely hampered by poor visibility, which was exacerbated in deepwater sections. Fortunately, warm temperatures accelerated gut fermentation and bloating, bringing many individuals to the surface.

Although rotenone was not without bias, the large number of fish collected made this the best method to assess the drop net's ability to describe fish assemblages. The number of species (two-sided paired t-test: $t = 1.512$, df = 2, $P = 0.270$) and $\log_{10}$(total abundance) ($t = -0.5444$, df = 2, $P = 0.641$; Table 6) estimated from the drop net (3-h effort) were similar to those estimated using rotenone. Some species were missed

TABLE 5.—Observed values of the test statistic D for Kolmogorov–Smirnov two-sample tests comparing fish size distributions between pairs of sampling techniques (drop net, two gill nets, beach seine, or rotenone application) in three riverine pools of the Pilbara region, Western Australia (standard effort duration = 3 h for all methods except rotenone; $*P < 0.05$; $**P < 0.01$). Gill nets captured no fish in pool B.

Pool	Technique	Drop net	Gill nets	Beach seine
A	Gill nets	0.93**		
	Beach seine	0.15**	0.87**	
	Rotenone	0.42**	0.52**	0.38**
B	Gill nets	—		
	Beach seine	0.10	—	
	Rotenone	0.12*	—	0.16**
C	Gill nets	0.69**		
	Beach seine	0.65**	0.85**	
	Rotenone	0.12*	0.56**	0.72**

by the drop net (Figure 3B); however, these species were in very low abundance within the study pools (abundance was < 1% of the total number of fish collected by use of rotenone; Table 2).

The size-frequency distribution of captured fish differed between the drop net and rotenone (Figure 4). Low abundance, rather than technique-related bias, is the probable explanation for the absence of large fish (>20 cm) in collections, as large fish have been caught in these ponds on other sampling occasions (authors' personal observations).

Differences in the fish collected with the drop net versus rotenone were most apparent at the community level (ordination of the species–abundance matrix; Figure 2). Site-related variation in the accuracy of the drop net relative to rotenone was also evident; for example, the drop net provided the most accurate description of the fish community at pool B (which only contained one species), revealing that the net's accuracy declined as the complexity of the fish community increased. An examination of the raw data (Table 2) indicated that the drop net underestimated the abundance of Hyrtl's tandan. Interestingly, although site-related trends in abundance suggested that the efficiency of the beach seine increased as habitat complexity decreased (pool C), the ordination revealed that the drop net collected a fish community that was more similar to that collected via rotenone (Figure 2). Although the accuracy of the drop net declined as community complexity increased, the drop-net collections still adequately reflected site-related differences in the fish community (Figure 2). Note that patterns were similar when data were proportionally transformed prior to ordination, removing the effect of different total abundances associated with the different level of effort.

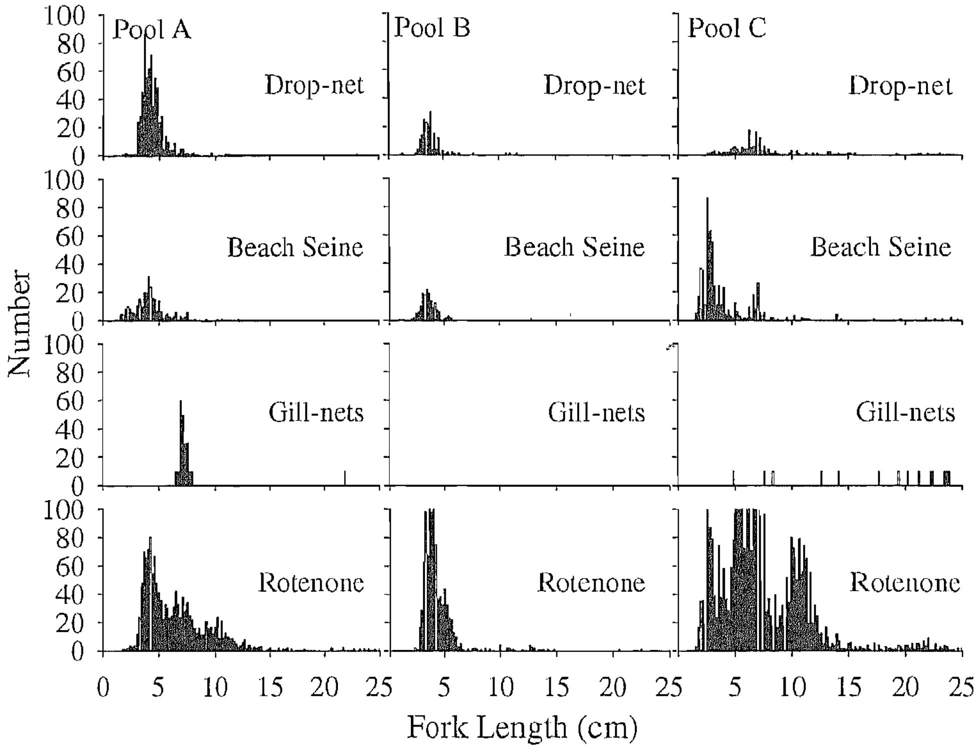

FIGURE 4.—Size-frequency distributions (fork length, cm) of fish (pooled across species) caught by use of dropnetting, gillnetting, and beach seining (standard effort duration = 3 h) at three pools in the Pilbara region of Western Australia during 2002. Size distributions of fish collected after rotenone addition are also depicted. Gill-net data were multiplied by 10 to increase visibility; the large cohort of 5–7-cm fish collected by rotenone at pool C is cropped at 100 fish.

Discussion

Efficiency

For the same duration of effort, the specially modified drop net and the beach seine generated similar descriptions of the fish community; panel gill nets collected a subset of the fish obtained by these methods. The high efficiency of the seine in comparison with a large drop net has been reported in estuarine studies (Kjelson and Johnson 1974; Gilmore et al. 1978) but was unexpected here due to anticipated problems associated with use of seines in complex habitats (Kushlan 1974; Dewey et al. 1989; Casselman et al. 1990). The unexpected level of seine efficiency could be attributable to the small size of the pools studied and their varying levels of habitat complexity. Small pools were chosen to minimize the impact associated with the use of rotenone, and this pool size may have improved seine efficiency because little open water was available as refuge for fleeing fish. This study was not designed to examine habitat-related differences in efficiency; however, efficiency of the beach seine (i.e., relative abundance in comparison with drop-net collections) notably increased with decreasing habitat complexity. The seine became increasingly easy to use as the structural complexity of the pools decreased, allowing a larger area to be swept during 3 h.

TABLE 6.—Total fish abundance and $\log_{10}$(total abundance) estimated by use of a drop net or rotenone application within three riverine pools of the Pilbara region, Western Australia. Drop-net abundance is based on 3 h of effort (three sets of the net).

	Abundance		$\log_{10}$ (abundance)	
Pool	Drop net	Rotenone	Drop net	Rotenone
A	3,525	1,353	3.547	3.132
B	1,641	988	3.215	2.995
C	1,865	3,650	3.271	3.562

Variance in the fish community across sites also caused trends in the efficiency of the fishing techniques used. When the community was very simple (containing only one species), differences between the drop net and beach seine were minimal and the two techniques obtained similar abundances, species richness, size-frequency distributions, and species–abundance matrices (ordination of the fish community in two-dimensional space). However, even in this simple community, the bias associated with gill nets was apparent. Gill nets failed to collect the one species that was present, providing further evidence of a strong bias toward medium- to large-sized individuals of pelagic species. The size-related bias of gill nets has been well documented (Casselman et al. 1990; Knight and Bain 1996).

Variance in the efficiency of fishing techniques among habitat types (Casselman et al. 1990; Knight and Bain 1996), species types (Kjelson and Johnson 1974; Connolly 1994), and size-classes (Casselman et al. 1990; Knight and Bain 1996) is well known. Most researchers attempt to overcome habitat-related biases by using a variety of techniques in the habitats where they are most effective. However, problems will arise if habitat types change (spatially or temporally), because variance in efficiency will introduce error into estimates of the fish community. Temporal studies of ephemeral systems are a case in point; such studies require techniques that can sample a range of habitat types with similar efficiency. For such systems, we recommend using a drop net (such as that described in this paper) in preference to a beach seine. However, if spatial and/or temporal changes in habitat are expected to be minimal, we recommend using a beach seine due to the minimal gear requirements. When absolute (rather than relative) estimates are required, then the drop net is preferable due to its enhanced ability to trap fish within a precisely known area (Lyons 1986); other studies have also reported that higher fish densities were collected in drop nets than in seines (Kjelson and Johnson 1974; Gilmore et al. 1978). Gill nets should be deployed in conjunction with drop nets to collect large size-classes that are in low abundance and to sample water that is deeper than 2 m.

Accuracy

Rotenone was not a completely unbiased estimator of the fish community. For example, 1 of the 12 species of fish that inhabited the study pools (empire gudgeon) was found to be partially resistant to rotenone. In addition, the collection of fish was significantly hampered by the presence of macrophytes, muddy and rocky substrates, deep water, and poor visibility. Small size-classes (i.e., fish < 3 cm) were the hardest to collect. Poor collection of small fish after application of a toxicant has been reported elsewhere (Henley 1967; Shireman et al. 1981; Bayley and Austen 1988) and is thought to be linked to their reduced buoyancy and increased likelihood of entanglement in vegetation (Shireman et al. 1981). In this study, the collection of fish for only 24 h postapplication probably accentuated these shortcomings. Other authors (Henley 1967; Pot et al. 1984; Jacobsen and Kushlan 1987) suggested that at least 3 d are required to collect most of the fish that succumb to rotenone. However, even if prolonged gut fermentation and associated bloating bring many fish to the surface (Shireman et al. 1981), any small fish that are trapped in aquatic vegetation may still be difficult to collect.

Even with bias, rotenone collected three times the number of fish collected by the other three methods combined and was therefore the best method to assess the drop net's ability to describe the fish community. In sampling between 4.3% and 16.5% of a pool's surface area (3-h effort), the drop net yielded species richness and total fish abundance estimates ($\log_{10}$ transformed) that were similar to those produced by rotenone application. Some species were missed by the drop net; however, they were in very low abundance within the study pools. Visual comparison of the fish assemblage collected by both methods in two-dimensional space (i.e., ordination of species–abundance matrix) revealed that the drop net accurately depicted site-related differences in the fish communities.

The drop net underestimated the abundance of one benthic species, Hyrtl's tandan. Hyrtl's tandan are particularly active at night (Allen et al. 2002; Pusey et al. 2004, personal observation) and may have escaped capture during daylight hours by resting on or burying within the mud. Alternatively, individuals of this species may have congregated in an area or habitat that was not sampled by the drop net.

Comparison with rotenone collections indicated that the drop net did not collect many of the relatively large (>10-cm) fish. Failure to collect large size-classes was not due to a technique-related bias but was a consequence of the rarity of these fish. If certain size-classes are in low abundance, then they are likely to remain undetected. Therefore, gill nets should be used in conjunction with drop nets to document the upper size range of fish.

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