Freshwater fish communities in Northland and methods for setting minimum flows

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Cover photograph of the North River by Jody Richardson

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Abstract

Richardson, J. & Jowett, I. G. 1998: Freshwater fish communities in Northland and methods for setting minimum flows. ***NIWA Technical Report 25.*** **40 p.**

The distribution and density of native fish was determined by single-pass electroshocking twenty 3 m^2 quadrats in each of eight Northland rivers. The fish community in each river consisted of eels, torrentfish, bullies, and smelt, with lampreys being caught infrequently. The number of fish caught by single pass electric fishing was unusually high (average of 2.2 fish per square metre) compared with other areas of New Zealand (average less than 0.5 fish per square metre). Fish distribution and density were not related to the location or instream characteristics of the rivers.

Habitat preference curves derived for the common Northland species were generally similar to curves derived from nationwide data; all the data were combined to develop composite curves for each species for future application.

The instream flow incremental methodology (IFIM) provides water managers with a system that combines hydraulic and habitat preference data into a form that can be used to assess the effects of different flows on the habitat of stream biota. It provides a more rational, biological approach to water allocation than those based on hydrological principles by taking into consideration the hydraulic response of the river to changes in flow and the potential effects of that on the biota. We recommend that IFIM be used in Northland to assess minimum flow requirements.

Fish species can be divided into habitat guilds; edge-dwelling (Cran's bullies), fast-water (torrentfish), or intermediate (common bullies) guilds. Habitat preferences (depth and velocity) of fish in the intermediate guild are an appropriate criterion for determining minimum flow requirements using IFIM. This will maintain some habitat for the edge-dwelling and fast-water guilds, as well as sufficient flow for food sources for fish.

In the longer term, we recommend the development of a regional method along the lines of those developed for Taranaki and Wellington Regional Councils, but based on native fish habitat requirements rather than those for trout. This method would be easier and less expensive to apply than IFIM.

Introduction

The Northland Conservancy of the Department of Conservation (DOC) covers 12 600 km^2 of the northern North Island from Kaipara Harbour to Cape Reinga. Water management for the region is administered by the Northland Regional Council under the Resource Management Act 1991. The region has many small river catchments and limited run-of-the-river water resources; the 1:5 year drought flow is estimated to be just 21.5 $m^3.s^{-1}$ (Poynter 1987). With its temperate to subtropical climate, suitable for dairying, forestry, and, increasingly, horticulture, there are high potential demands on this limited resource.

Applications for water abstraction have escalated in Northland, particularly during 1993–94, a trend the Northland Regional Council expects to continue for some years. However, lack of information on habitat preferences of Northland fish species limits the methods water managers can use to predict likely effects of abstractions on fish. DOC therefore requested NIWA to undertake a fisheries study in Northland with the following objectives. By sampling six or more rivers, to examine and compare species distribution and density with existing knowledge to identify factors that influence the distribution and density of native fish in Northland.

- To develop habitat preference curves for common Northland native fish species and to compare these with preference curves developed from data collected around the rest of New Zealand.
- To discuss the application and flow management implications of these habitat preferences when using hydraulic habitat modelling procedures.
- To discuss the relative merits of the mean annual minimum flow as a minimum flow standard.

Distribution, density, and habitat of Northland fish

Methods

Study sites

Single locations on eight Northland rivers, chosen by Department of Conservation staff, were visited in March 1995 (Figure 1, Table 1). Both the North River and Punaruku Stream flow to the east coast, whereas the Victoria River flows north to Rangaunu Harbour. The Waipapa and Whakanekeneke Rivers are tributaries of the westward flowing Waihou River, and the remaining three rivers are within the large westward draining Wairoa River catchment. Distance from the sea at the sites, measured along the water course, ranged from 5 to 162 km, and altitude varied from 15 to 90 m above sea level. Stream order was assigned as follows; streams were classified as first order if there were no upstream tributaries marked on the NZMS260 maps, second order below the junction of two first order tributaries, third order below the junction of two second order streams, and so on.

The catchments of five rivers contained more than 65% native forest, with one, the Waipapa, being 100% native forest. Some native forest was also present in the remaining three catchments, but most vegetation was pasture and exotic forest. Riparian vegetation was mainly grassy banks, with scattered trees and some exposed riverbed. Most of the rivers were small (5–8 m wide), and shallow enough to wade easily.

Fish distribution and density

The distribution and density of fish in these Northland rivers were determined by sampling a variety of habitats using a stratified transect technique (Glova 1982). In each river, 20 individual quadrats of 3 m^2 each were single-pass electroshocked during daylight hours. The 20 quadrats were subjectively chosen to include all the habitat types available at each site, except water deeper than about 1 m which could not be efficiently electroshocked. Fish caught were identified, counted, and the density (numbers per square metre) was calculated by dividing the number of fish caught by the area sampled. This information was compared among the eight rivers, with similar data from a nationwide study of native fish habitat from 38 rivers (Jowett & Richardson 1996), and with information from the New Zealand freshwater fish database (McDowall & Richardson 1983).

***Table 1*: Location and physical attributes of the study sites on eight Northland rivers (N, native forest; E, exotic forest; P, pasture; S, scrubland; X, exposed riverbed)**

River	NZMS260 map reference	Stream order	Inland distance (km)	Altitude (m)	Catchment vegetation (%)	Riparian vegetation (%)
North	Q07 326 812	3	22	50	N 70 P 30	P 60 S 30 X 10
Punaruku	Q05 303 447	3	5	20	N 80 E 20	N 80 P 10 X 10
Victoria	004 500 712	3	45	90	N 65 E 25 P 10	S 70 P 30
Waipapa	P05 730 581	4	21	15	N 100	N 50 X 50
Whakanekeneke	P05 797 549	3	29	50	P 60 N 40	P 70 N 10 S 10 X 10
Kaihu	P07 717 055	5	72	70	E 40 N 30 P 30	P 85 S 10 X 5
Hamenga	P06 995 137	3	139	40	N 90 P 10	P 80 S 15 X 5
Mangakahia	P06 880 187	5	153	35	N 30 E 20 S 10 P 30	P 60 S 20 X 20

Habitat preferences

Animals and plants are assumed to show habitat preferences by their relative abundance in different surroundings or climate. If a species is more abundant or grows better under certain conditions, it is assumed to have a preference for those conditions relative to other available choices. In the aquatic environment, instream habitat usually refers to the physical habitat (water velocity, depth, substrate, and perhaps cover) because these habitat attributes are the most easily recognised and measured. In the absence of confounding off-site factors, animals are most abundant where habitat quality is best, in low numbers where the habitat is poor, and absent from totally unsuitable habitat. If the characteristics of habitats occupied by many individuals of a species are surveyed, it is possible to determine the relative quality of different habitats from the abundance of the species of interest. Habitat preference curves provide a means of describing what is considered to be "good" habitat for particular guilds, taxa, species, or life stages of species. The following method was used to determine habitat preferences of native fish in Northland.

Within each of the 3 m^2 quadrats, four depth and velocity measurements were taken and mean values calculated. Substrate composition was also assessed within each quadrat by measuring 10 particles using the Wolman walk method (Wolman 1954) and then calculating the median particle size.

Habitat preference curves for depth, velocity, and substrate were developed for those species present in sufficient numbers (more than 50 individuals). A preference was determined by comparing the habitat in which fish were found (habitat use) with the habitat that was sampled (habitat availability). Curves for the frequency of habitat use and availability were generated from kernel smoothed density distributions (Johnson & Kotz 1971, Silverman 1986, Aptech Systems Inc. 1991) of water depth, velocity, and substrate. If the habitat use and availability curves were similar, then the species was uniformly distributed throughout the available habitat, and therefore exhibited no particular preference for any type of habitat. Alternatively, if the habitat use and availability curves were different, then the species was showing a preference for a particular feature of the habitat.

Preference curves were derived by dividing the frequency of use by the frequency of habitat availability (Bovee 1986). The curves were scaled to a maximum preference value of 1 by dividing by the maximum ordinate. This often creates anomalies if the sampling frequency is low because the difference is divided by a small number, giving an anomalously high preference value. For this reason we have presented curves of both habitat use and habitat availability and the derived preferences (Figures 2–7).

The habitat preference curves derived from Northland rivers were compared with those developed by the same method from data collected in 34 other rivers (Jowett & Richardson 1995). Data from the 34 rivers were combined with the data from Northland, the Onekaka River in Golden Bay (Richardson & Jowett 1995), and another 4 rivers surveyed in 1995 (NIWA, unpublished data) to give composite habitat suitability curves for each species.

Results

Fish distribution and density

A total of nine species and 1061 individual fish were caught from the 480 m^2 of water electroshocked in the eight Northland rivers (Table 2). Six species, longfin eel (*Anguilla dieffenbachii*), shortfin eel (*A. australis)*, torrentfish (*Cheimarrichthys fosteri*), Cran's bully (*Gobiomorphus basalis*), redfin bully (*G. huttoni*), and common smelt (*Retropinna*

retropinna), accounted for 99% of the total fish numbers. Three other species, common bully (*G. cotidianus*), giant bully (*G. gobioides*), and juvenile lamprey (*Geotria australis*), were captured infrequently.

All rivers contained similar fish assemblages. Both species of eel, bullies, and usually torrentfish and common smelt were present in all rivers. Cran's bullies and redfin bullies were rarely encountered together, with Cran's bullies mostly found at the sites which were the furthest inland. Neither the total number of species nor the density of fish was related to stream order, inland distance, elevation, percentage of native forest in the catchment, or measured instream characteristics (average depth, velocity, or substrate size) of the eight rivers (Spearman rank correlation, $P > 0.05$ in each case), as might be expected from such a low number of rivers within a relatively small geographical and altitudinal range (Tables 1 and 3).

The average density of fish caught by single pass electric fishing in Northland was very high compared with average fish densities obtained from other sources; 2.21 fish per m^2 in Northland, 0.42 fish per m^2 from the 34 rivers dataset (Jowett & Richardson 1996), 0.32 fish per m^2 from electric fishing records in the New Zealand freshwater fish database (McDowall & Richardson 1983), and 0.33 fish per m^2 in Kahurangi National Park (Jowett *et al.* in press). To some extent, this reflects the low altitude of the Northland sites (15–90 m), as this feature and the diadromous habit of most native fish were important factors influencing species distribution and density in New Zealand rivers (McDowall 1993, Jowett & Richardson 1996, McDowall 1996, Jowett *et al.* in press).

***Table 2*: Distribution and density of native fish in eight Northland rivers (-, absent; +, 0.01 to 0.15 fish per m^2; ++, 0.16 to 0.3 fish per m^2; +++, > 0.3 fish per m^2)**

River	Longfin eel	Shortfin eel	Torrent-fish	Cran's bully	Redfin bully	Common smelt	Common bully	Lamp-rey	Giant bully
North	+	++	-	+++	+	-	-	-	-
Punaruku	+++	++	-*	-	+++	+++	-	+	+
Victoria	+	+	++	-	+++	+++	+	-	-
Waipapa	+	+++	++	-	+++	++	-	+	-
Whakanekeneke	+++	++	+++	-	++	++	-	-	-
Kaihu	+	+++	++	+++	-	-*	+	+	-
Hamenga	+++	++	+	+++	-	-	-	-	-
Mangakahia	++	+++	+	+++	-	-*	-	+	-

* Probably present, but none caught.

Table 3: **Average depth, velocity, and substrate size, and fish data for the eight study rivers**

River	Depth (m)	Velocity ($m.s^{-1}$)	Substrate size (mm)	Total number of species	Total fish per m^2
North	0.22	0.25	18.6	4	2.07
Punaruku	0.27	0.24	24.4	6	2.05
Victoria	0.24	0.28	61.5	6	2.22
Waipapa	0.34	0.30	24.9	6	2.20
Whakanekeneke	0.29	0.34	82.3	5	1.77
Kaihu	0.30	0.28	87.4	6	2.47
Hamenga	0.27	0.11	30.2	4	3.92
Mangakahia	0.30	0.50	76.8	5	1.00

Habitat preferences

Among all 160 sampling quadrats, water depths varied from 0.05 to 0.85 m, velocities from 0 to 1.34 $m.s^{-1}$, and median substrate size from 2 to 181 mm. The average depth decreased and velocities and substrate size increased with habitat type from pool and backwater to run to riffle (Table 4). Generally, the number of fish in backwaters and pools was lower than that in runs and riffles. Torrentfish and longfin eels were most common in riffles, whereas shortfin eels and common smelt preferred runs. Cran's bullies and redfin bullies were equally abundant in runs and riffles.

Habitat preference curves were developed for the six species for which there were sufficient data, namely, longfin and shortfin eels, torrentfish, Cran's and redfin bullies, and common smelt. These curves describe the habitat types in which the fish were found, and were similar to those from the other 34 rivers (Jowett & Richardson 1995), and to the composite curves (Figures 2–7). For example, longfin eels (Figure 2) preferred shallow depths and moderate to high velocities, as are typically found in riffles. Depth preferences of longfin eels were similar throughout New Zealand, but Northland eels had more clearly defined velocity preferences than eels from other areas. Little substrate preference was shown by longfin eels anywhere.

Table 4: **Average water depths, velocities and substrate sizes, and the percentage of each fish species caught in each habitat type sampled in Northland**

	Backwater (n = 3)	Pool (n = 39)	Run (n = 61)	Riffle (n = 57)
Depth (m)	0.28	0.44	0.27	0.18
Velocity (m s^{-1})	0.01	0.05	0.22	0.54
Substrate size (mm)	19.8	37.8	44.5	68.0
Longfin eel (n = 136)	2.2	5.1	26.5	66.2
Shortfin eel (n = 185)	4.3	26.5	48.6	20.6
Torrentfish (n = 94)	0.0	4.3	13.8	81.9
Cran's bully (n = 370)	5.4	11.3	38.4	44.9
Redfin bully (n = 171)	1.8	7.6	46.2	44.4
Common smelt (n = 91)	1.1	33.0	51.6	14.3
Common bully (n = 3)	0.0	67.0	33.0	0.0
Lamprey (n = 10)	20.0	30.0	50.0	0.0
Giant bully (n = 1)	0.0	0.0	100.0	0.0
All species (n = 1061)	3.5	14.1	38.9	43.5

Shortfin eels (Figure 3) also preferred shallow depths and the fine substrate usually present in the run/pool habitat where they were most abundant. The similarity of the velocity available and velocity used curves in Figure 3 suggests that shortfin eels do not have a strong velocity preference.

In contrast, torrentfish had definite velocity preferences, and were most abundant in velocities greater than 0.75 m.s^{-1} (Figure 4). Preferred depths were between 0.2 and 0.4 m, and this combination is typical of their favoured riffle habitat. Substrate preferences indicate that a variety of sizes were used by torrentfish, and that velocity and depth are probably more important considerations.

Both Cran's and redfin bullies (Figures 5 & 6) showed similar preferences; shallow water, moderate to low velocities, and gravel-sized substrate. This is typical of all the bully species, except bluegill bullies which prefer swifter velocities and deeper water (Jowett & Richardson 1995). Velocity and substrate preferences for redfin bullies in Northland were very broad, suggesting depth is the most important instream characteristic for this species.

In contrast to most other native species, smelt preferred deep water (Figure 7) and many were seen in water more than 1 m deep that was not sampled. Smelt preferred low velocities, and generally avoided coarse substrate.

Discussion

Factors influencing fish distribution and density

This survey of fish communities in Northland rivers was not specifically targeted at all fish species or habitats. All sampling occurred in second to fourth order streams during daylight hours; fish may occupy different habitats at night. Nevertheless, this study showed that the communities were made up of a limited number of common riverine species. Similar fish assemblages and conclusions were found by sampling rivers nationwide (Jowett & Richardson 1996) and by intensively sampling several tributaries in the Grey River catchment (Jowett *et al.* 1996).

Landuse is often cited as a determinant of fish distribution. For example, Hanchet (1990) and Swales & West (1991) found that banded kokopu were present in catchments with native forest and absent from pastoral catchments. A survey of Kahurangi National Park showed that banded kokopu were very common in small forested streams, but an examination of records in the New Zealand freshwater fish database indicated that banded kokopu were not limited to forested streams (Jowett *et al.* in press). A comparison of fish fauna in the Grey River catchment (Jowett *et al.* 1996) showed that fish communities did not differ between native, exotic, pastoral, and mined catchments. Likewise, in this survey of Northland streams, we sampled both native and pastoral catchments and found similar fish communities. Although records from the New Zealand freshwater fish database show that banded kokopu and koaro are relatively plentiful in Northland, none were found in this study. However, the streams sampled in this study were large streams that could be potential sources of irrigation water and were bigger than those sampled by Hanchet (1990) or Swales & West (1991). This, together with known habitat preferences of banded kokopu (McDowall 1990, Jowett *et al.* in press), suggests they are likely to be present in first order tributaries and use the main channel only for passage to these habitats.

Studies of single catchments such as the Mokau (Hayes *et al.* 1989), Mohaka (Strickland 1985), Kakanui (Jowett 1994b), and Waipara (Richardson & Jowett 1994) have demonstrated the influence of diadromy on fish distribution, and nationwide studies have shown that this influence is widespread (Minns 1990, McDowall 1993, Jowett & Richardson 1996). Some species are confined to estuaries and low gradient deep water, and others penetrate to the very headwaters of rivers and streams. Jowett & Richardson (1996) classified sites according to species diversity and abundance. They found that diadromous species were most common at low elevations and gradually disappeared at higher elevations. High diversity and abundance occurred in lowland sites below 40 m. Above this, there was a similar fish assemblage but lower levels of abundance. At an elevation of about 170 m, upland species began to predominate. Northland sites fell into the lowland and mid-range elevation categories, so we expected, and found, a range of common riverine species — eels, torrentfish, and bullies. Jowett & Richardson (1996) suggested that fish abundance was highest at sites with gravel substrate. This was the predominant substrate type in Northland, and may have contributed to the high fish densities.

Habitat preferences

Habitat preferences are derived from comparisons of the habitat used by fish and the available habitat and so reflect a preference relative to the other available options. Because different types of habitat are available in different rivers, it is reasonable to expect that there will be some difference between habitat preference curves derived from different rivers or groups of rivers. Differences are particularly noticeable where sample sizes are small or where fish are generalists without well-defined habitat preferences. We believe that any preference differences are a result of the availability of different habitats and the restricted choice of habitats available to fish, either in Northland or elsewhere, rather than differences in actual preferences between fish in different rivers.

Habitat preference curves derived from Northland data were generally similar to those derived from rivers in the 34 rivers survey (Jowett & Richardson 1995). Exceptions were as follows.

- Longfin eels in Northland showed a preference for velocities of about 0.5 $m.s^{-1}$ but, there was little velocity preference evident in the 34 rivers data.
- Shortfin eels in Northland showed a low velocity preference, whereas the 34 rivers data indicated a preference for higher velocities.
- Torrentfish in Northland were associated with large cobble substrate, whereas torrentfish in the 34 rivers data were found in gravel substrate.
- Redfin bullies in Northland were associated with gravel and small cobble substrate, whereas in the 34 rivers they were found associated with boulders.

Both longfin and shortfin eels tend to be generalists and are able to live within the substrate in a wide variety of velocities. The velocity preferences probably indicate the distribution of suitable substrate conditions rather than a velocity preference.

The most likely explanation for the difference in substrate preferences for torrentfish and redfin bullies is the relationships that exist between substrate size and velocity in the different rivers, with the velocity preference taking precedence over any substrate preference. In Northland, the high velocities preferred by torrentfish were found only in association with boulders or large cobbles, whereas in the 34 rivers, high velocities were found in steep gravel riffles. On the other hand, redfin bullies prefer low to moderate velocities and in Northland these were found associated with finer substrate than in the 34 rivers. Another possibility is that redfin bullies select coarser substrate in the presence of trout, but this idea needs to be tested. In terms of instream flow assessments, substrate is less important than either water depth or velocity, because it is relatively uniform within pools, runs, and riffles, and does not vary with flow.

Overall, we believe that habitat preferences should be determined by sampling as many fish as possible in a wide range of habitats. To this end, we have combined the Northland data with other New Zealand data to develop curves for future application.

Application of the instream flow incremental methodology (IFIM) for instream flow assessment

Introduction

The basic concepts of hydraulic modelling of river flow and of aquatic species having habitat preferences are readily accepted and are routinely applied, the former by engineers, the latter by biologists or anglers who capture fish. The two concepts have been combined in the instream flow incremental methodology (IFIM) to provide a system that processes diverse data into a form that can be used to assess the effect of different levels of flow on the habitat of stream fish and insects. The measurement of the amount of suitable habitat in a river is known as the weighted usable area (WUA). Habitat preference curves form a base for the calculation of WUA and assessment of instream flow requirements. Once habitat preference curves or criteria are defined for a *target* species, they can be applied to hydraulic data and the amount of suitable habitat or WUA calculated for a range of flows. Assessments are then made of the way habitat changes with flow and typically the curves are examined to find an optimum or point of inflection (Figure 8). A minimum flow is then selected. Usually, the minimum flow will be at the point where further flow reductions will cause usable habitat to fall rapidly towards zero.

The intention of water management decisions based on IFIM is to maintain aquatic life, implying a connection between habitat and aquatic populations. The apparent complexity of the IFIM process has created suspicion about its validity, relationship to aquatic populations, and the flow recommendations that result. However, the bottom line of IFIM flow recommendations is that if there is no suitable habitat the species will cease to exist and in the extreme case — no water, no fish.

IFIM is not without its pitfalls. Habitat preference information may not be appropriate, or may neglect essential life stages or requirements, for example, toxic pollutants or extreme events. However, the requirements of a stream ecosystem can be specified in terms of habitat measurements. Algal and aquatic invertebrate production is highest in shallow riffles, while salmonid spawning habitat requires gravels, shallow water, and moderate velocities. Both exotic and native fish have well-defined depth and velocity preferences (Jowett 1993a, Jowett & Richardson 1995). The key to successful flow recommendations is to provide sufficient habitat for the maintenance of all life stages of target species, as well as considering the requirements of the stream ecosystem as a whole. Selection of an appropriate target species or group of species can also provide habitat requirements that maintain or enhance biodiversity.

Target species

In North America, the target species is usually the commercially valuable salmon. In New Zealand, it is more difficult to decide on a target species. In angling rivers, trout are the usual target species and it has been assumed that if there is sufficient flow for trout, there will be sufficient for native fish. More recently, flow assessments have been based on native fish habitat requirements (Jowett & Richardson 1995, Richardson & Jowett 1995).

With an average of five species per site, there is the question of which species should be used. Jowett & Richardson (1995) divided species into habitat guilds. There were the species that lived along stream margins, an edge-dwelling guild; there were also species that lived in fast water — bluegill bullies and torrentfish, species that lived anywhere like eels and trout, and, last of all, a few species whose habitat preferences were intermediate between edge-dwelling and fast-water guilds. Jowett & Richardson (1995) suggested that flow recommendations should be based on an intermediate species, such as common bullies, because provision of habitat intermediate between that of fast-water and edge-dwelling guilds is a compromise likely to support higher total fish numbers and biodiversity. This recommendation is supported by recent findings (Jowett & Richardson 1996) that total fish density was correlated with the density of common bullies, even though common bullies were not the most numerous species.

Application of habitat preference curves for species of the three guilds (Jowett 1994a, 1994b) has shown that optimum values and points of inflection are difficult to define for fast-water species, appear unreasonably low for edge-dwelling species, but appear to be within the expected range of values for the intermediate habitat guild (Figure 8).

River management, mean annual minimum flow, and regional minimum flow estimation

Instream flow management implies that there is a resource to be protected and that there is some way to measure or specify levels of protection for that resource. Legislation provides the framework within which to consider the goals of instream flow management. DOC's responsibilities for freshwater fish and their habitats are guided by the Conservation Act, specifically Section 6 (a, b) "To preserve as far as is possible all indigenous freshwater fisheries, and to protect recreational fisheries and freshwater fish habitat." The New Zealand Resource Management Act (RMA) requires that water be managed in a way that provides for the well-being of the community while sustaining the potential of natural and physical resources, safeguarding the life-supporting capacity of a river, and avoiding remedying, or mitigating adverse effects.

The RMA does not specify what life is to be supported and managers are required to decide what is relevant to a particular river system, although the protection of trout and salmon habitats is mentioned specifically in the RMA. A change to a river's flow regime will usually have some unavoidable effects on stream biota, albeit unmeasurable. The amount of available habitat for some species will be decreased, and available habitat for other species will increase, often with corresponding changes in total numbers. The provision of a minimum flow is a means of retaining the life supporting capacity of a stream. Aquatic populations are resilient and variable, and a realistic objective of sustainable management should ensure that the level of protection for aquatic species is adequate, rather than attempting to ensure that populations remain unchanged. This is because comparison of fish populations in different rivers shows that good fish populations can be sustained by widely differing flow regimes.

The previous discussion of IFIM focused on a method of assessing flow requirements in stream channels without reference to natural stream flow. This can be taken further and results of IFIM studies developed onto "rules of thumb" that allow quick and inexpensive flow management decisions based on natural flow regimes. The index of natural flow regime used is the mean annual minimum flow, which is the average of the annual minimum flows. The minimum flow can either be the instantaneous minimum flow or the 7-day low flow; the advantage of the former is its ease of calculation and the advantage of the latter is that "spikes" in the hydrological record have less influence on its value. The mean annual minimum flow is related statistically to the 1:5 year low flow. The advantage of the mean annual minimum flow is again its ease of calculation, and avoidance of any uncertainty about statistical distributions or extrapolations that may be inherent in 1:5 year low flow assessments. It may also have more biological relevance than the more extreme 1:5 year low flow. The hydraulic conditions at mean annual minimum flow may be a bottleneck for aquatic species that have life cycles of 3 to 5 years. For example, Jowett (1993a) showed that brown trout densities were related to the amount of adult habitat at mean annual minimum flow rather than to the amount of habitat at median flow or at mean flow.

Some stream ecologists, particularly those in South Africa and Australia, hypothesise that stream biota have adapted to the flow regime of particular streams or rivers, and in particular, they believe that biota have adapted to the low flows and floods that occur in the river with reasonable frequency. The outcome of this argument is that some stream ecologists suggest that the minimum flow should not fall below the mean annual minimum flow, or just the minimum flow, that is exceeded with a given frequency, say, 90% of the time. They also argue that the magnitude and frequency of flooding should not be altered. The intent of this method is to retain the stream biology status quo by taking a cautious approach.

Flow assessments based on instream habitat do not necessarily result in the same outcome as hydrological assessments. Proportionally, flow reductions in large streams result in less habitat loss than flow reductions in small streams. The following example illustrates how the effect of flow reductions is potentially more deleterious in small streams. Benthic invertebrates and native fish are typically found in run and riffle habitats with velocities of 0.3–0.7 $m.s^{-1}$ and depths of 0.05–0.5 m. If these are the habitat requirements, a stream will contain no suitable invertebrate or fish habitat if it is shallower than 0.05 m or flows with velocities less than 0.3 $m.s^{-1}$. At times, these limits can be approached in some small streams, but in larger streams there will be large areas that exceed these limits. Thus, a given percentage flow reduction in a small stream is more likely to reduce depths and velocities below lower limits than the same percentage reduction in a large stream.

Variation in minimum flow requirements with stream size was clearly demonstrated in studies of regional flow requirements for the Taranaki and Wellington Regional Councils (Jowett 1993b, 1993c). Habitat surveys in 13 and 16 rivers, respectively, were used to estimate flows that retained a minimum area of suitable habitat for trout and food production. In this case, the "standard" of minimum habitat quality was that 13% of the stream area should contain suitable food producing habitat. The analysis showed that in streams with a mean annual low flow of less than 0.5 $m^3.s^{-1}$, flows required to maintain the minimum habitat quality were greater than the mean annual low flow, whereas in streams larger than 1 $m^3.s^{-1}$, 50% of the mean annual low flow provided the minimum or better habitat quality. Interestingly, curves derived independently for both Taranaki and Wellington were very similar. These minimum flow guidelines suggested that mean annual minimum flows should not be reduced by water abstraction in streams with an annual minimum flow of less than 0.4–0.8 $m^3.s^{-1}$. This flow value is dependent upon both the habitat requirements and standard of instream habitat, and would be lower if a lower standard was acceptable and higher if a higher standard was required. The minimum flow requirement would change if the target species changed to one with different habitat preferences (e.g., native fish) or if the target species was varied with stream size, for example, native fish habitat in small streams and trout habitat in large streams.

Unfortunately, there are no quantitative case studies of fish populations before and after flow regulation, and assessments of impacts are based on subjective information.

Flow variability

Flow variability is usually considered ecologically desirable, though there is little scientific measurement of the effect of flow variability on fish populations. Jowett & Duncan (1990) concluded that New Zealand rivers with low flow variability tended to contain fauna that were associated with "clean" rivers and rivers of high flow variability contained invertebrates and algae that were typical of low velocity environments. In this context, low flow variability rivers had constant flows which were usually high and were subject to frequent but small flow perturbations. Rivers with high flow variability were those in which there were prolonged spells of low flow and less frequent flood flows that were large in comparison with the low flows. Thus, generally a steady flow with frequent perturbations will maintain more desirable "clean water" fauna than one with prolonged low flow and occasional floods.

Other studies have shown the deleterious effects of floods on fauna and flora. Floods can reduce trout stocks (Jowett & Richardson 1989), invertebrates (Quinn & Hickey 1990), and periphyton. However, not all floods produce this effect and native fish and brown trout seem to be particularly well adapted to surviving floods and taking advantage of the situation to feed on both terrestrial food and increased drift (Jowett & Richardson 1994).

Generally, the magnitude of flows required for flushing accumulated sediment and periphyton from the streambed is greater than can be provided by managing the amount of water abstracted from a river. Flow sharing above a certain minimum flow can be used to provide a degree of flow variability, but with current knowledge we cannot assess the relative benefits of this practice compared to the benefits of the flushing flows provided by freshes.

Factors controlling fish populations

The minimum flow may not necessarily be limiting fish populations, and certainly is not the only factor controlling fish populations. Studies of trout in the Kakanui River showed that the total adult population was regulated by recruitment and that, in turn, was controlled by the occurrence of floods during spawning and incubation (Jowett 1995). Low flows had no obvious effect on the trout population.

Food may also limit populations. Benthic invertebrate biomass was shown to be the single most important factor relating to trout abundance in different rivers (Jowett 1993a), and in the Kakanui River the distribution of adult trout mirrored benthic invertebrate abundance (Jowett 1995). Flow recommendations should consider habitat requirements for both adult trout and food production.

The influence of diadromy on native fish distribution is very evident (McDowall 1993, Jowett & Richardson 1996), but very little is known about the other factors controlling native fish abundance. New Zealand native fish appear to have evolved to cope with the varying flow conditions they experience in our rivers. Most galaxiids and eels are able to survive periods out of water and are capable of some overland movement. Many are also capable climbers and can penetrate to the headwaters of most rivers. The diadromous habit protects their early life stages from the riverine environment. Average fish densities in lowland areas are up to about 0.5 fish per m^2 (New Zealand freshwater fish database), with fish density reducing with elevation. The overwhelming influence of diadromy, the widespread distribution of the more common native species, and their well-defined preference for relatively shallow water habitats, suggest that fish density and species diversity will be controlled at a catchment level by diadromy, while instream habitat will control the distribution of fish within a river reach. Flows that provide adequate native fish habitat are therefore likely to maintain native fish populations, although some flow variation should be provided to ensure that these flows do not restrict food supplies. Juvenile trout, like native fish, occupy shallower water and feed on smaller food items than do adult trout. Their flow and food requirements were correspondingly lower than those for adult trout and were similar to those recommended as providing suitable habitat for native fish (Jowett 1994b, Jowett & Hayes 1994). Flow requirements for the invertebrate species that native fish prey upon are not known, but it is likely that these will be lower than those for adult trout.

Recommendations

We believe that minimum flows assessed on the basis of habitat provide a more rational approach to the allocation of water than one based on hydrological statistics, because habitat methods have a better biological basis. These methods require that flow requirements be considered in terms of explicit instream uses and values, and predict the flows required to maintain appropriate habitat. This results in a better and more balanced allocation of resources, especially as habitat-flow relationships are often non-linear.

We recommend that IFIM studies be used to assess minimum flow requirements with standards of protection defined according to the fish species present and value of the resource. Thus, flow requirements for each stream will be assessed from its hydraulic characteristics and the perceived value of the fish resource.

In the longer term, we recommend the development of a regional method along the lines of those developed for Taranaki and Wellington, but based on native fish habitat requirements rather than those for trout. This method would be easier and less expensive to apply than IFIM surveys.

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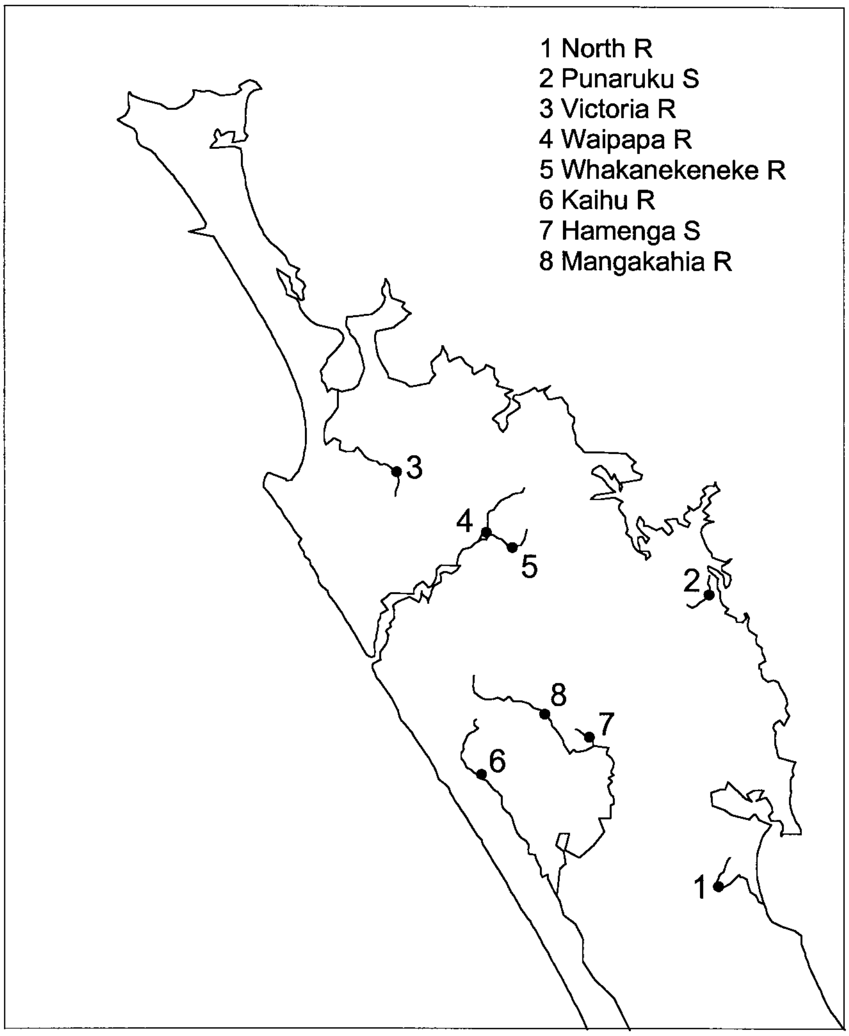
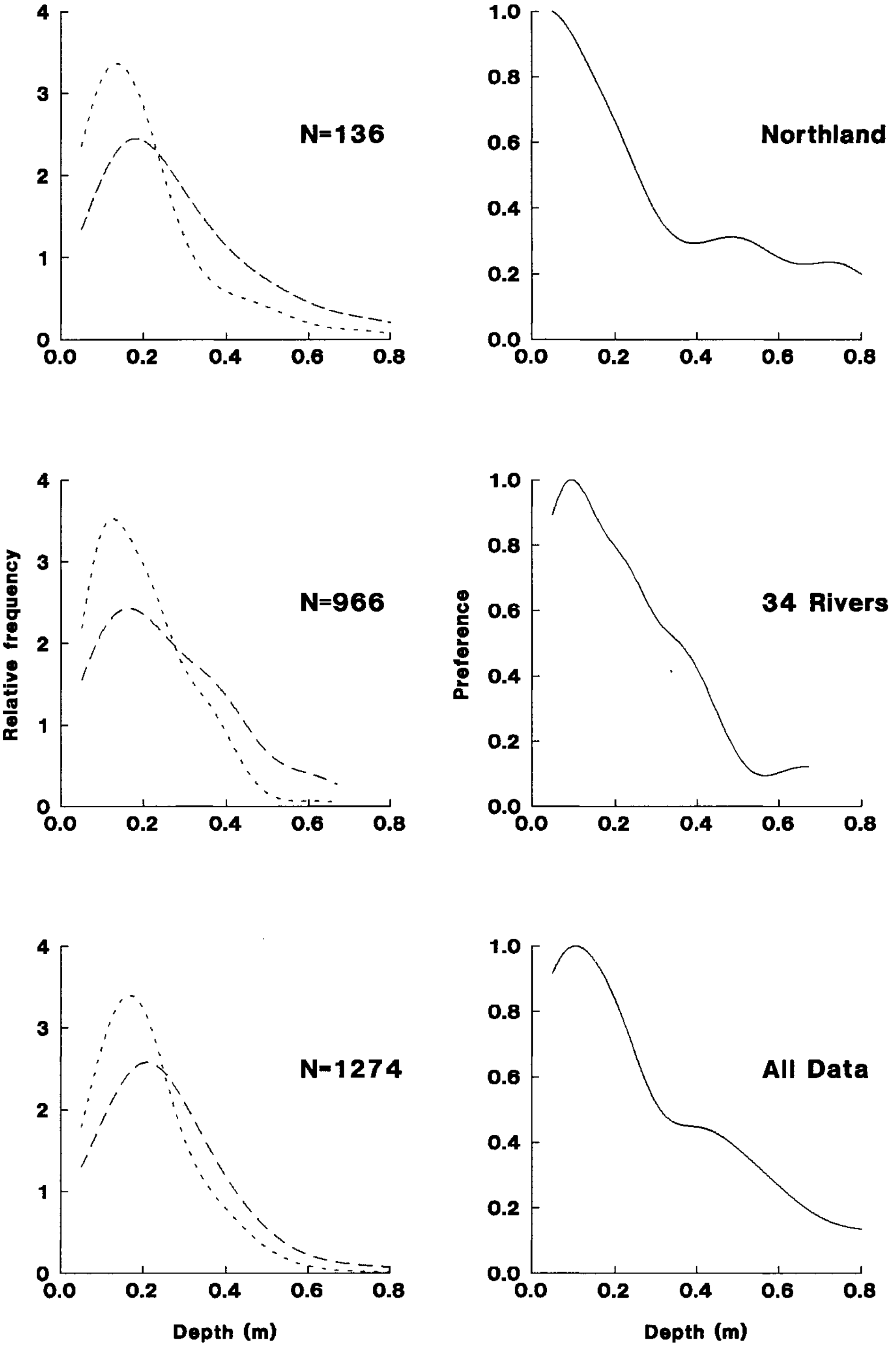
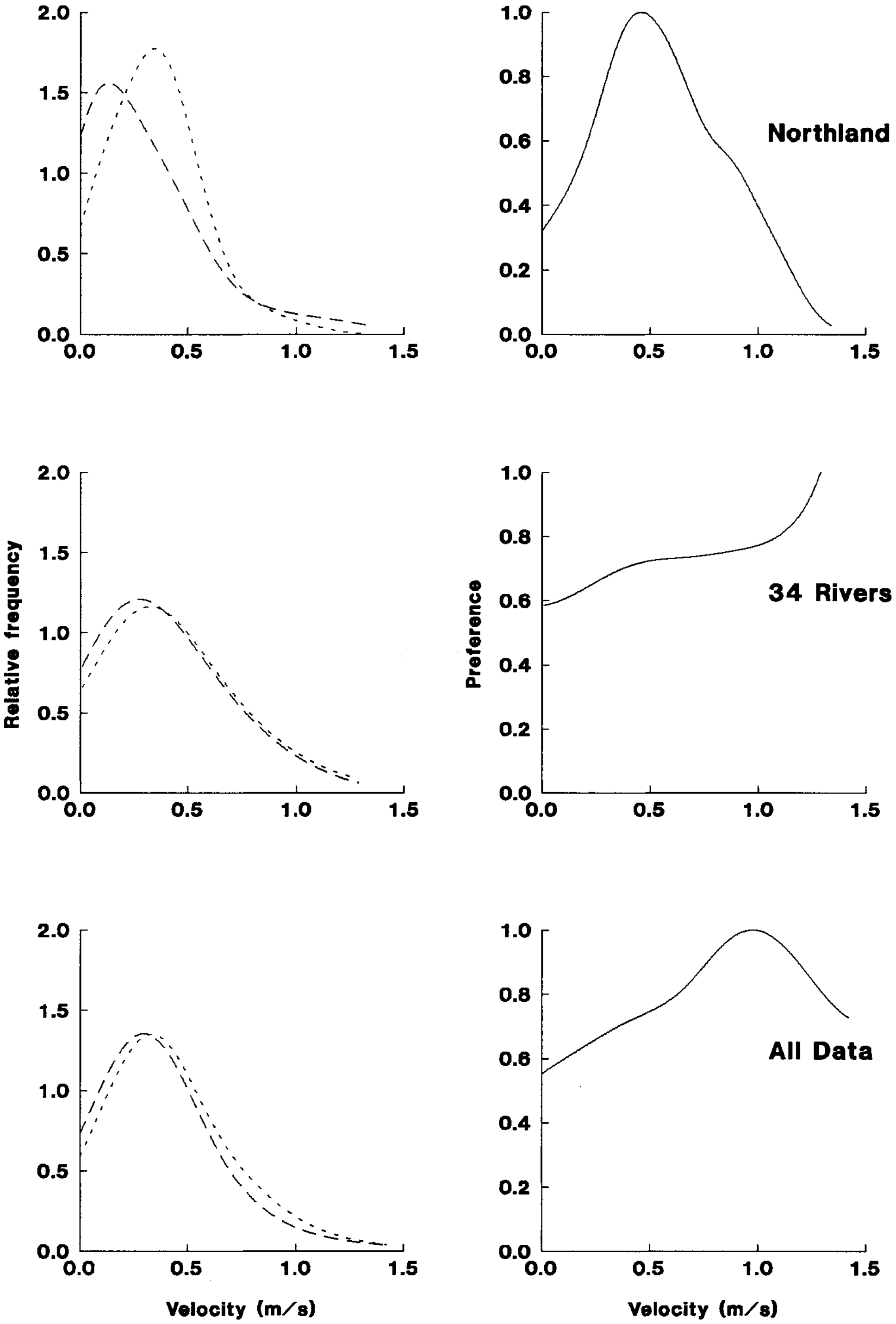


Figure 1**: Locations of the eight Northland rivers surveyed in March 1995.**



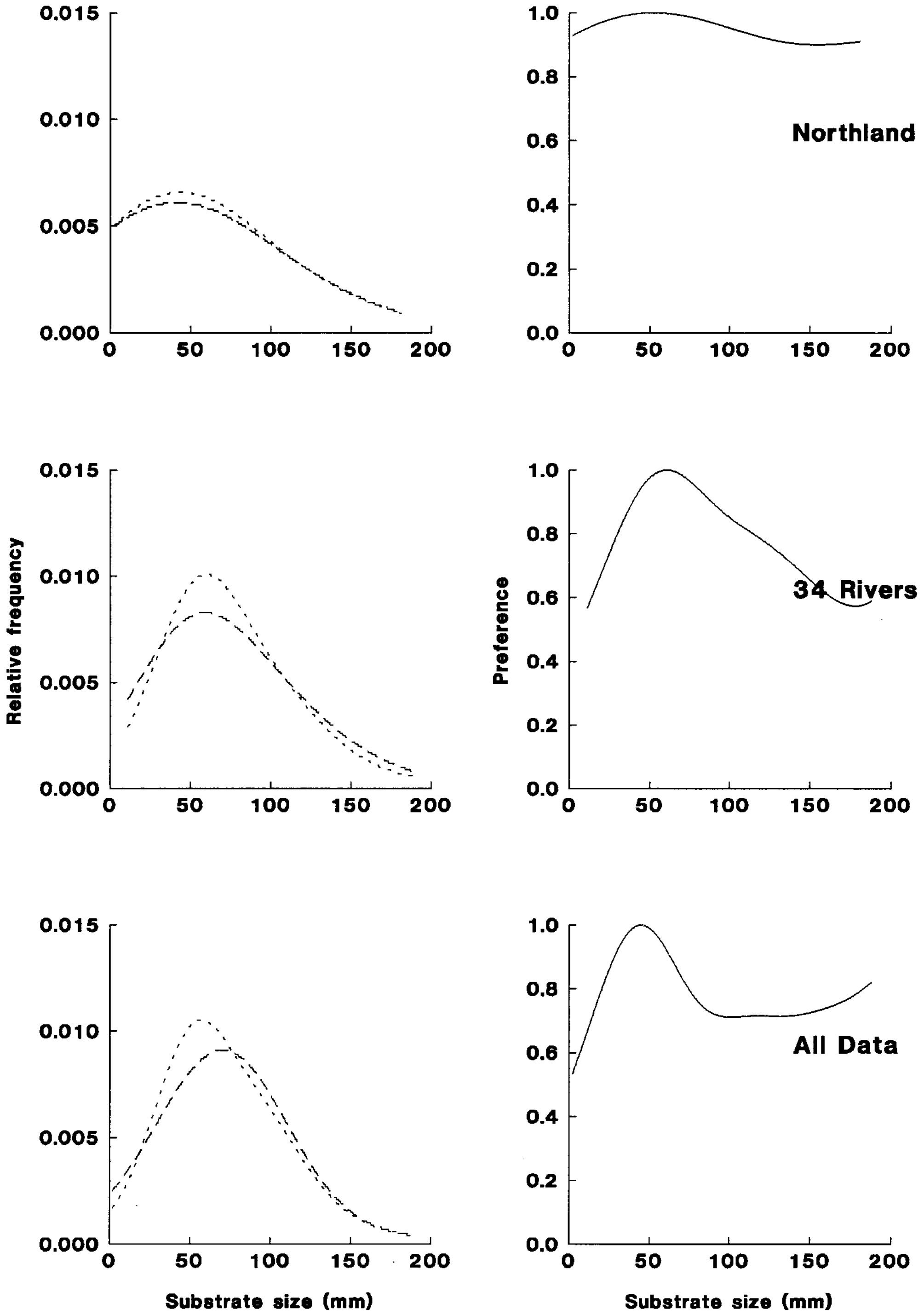
Longfinned eel

Figure 2: Depth, velocity, and substrate habitat preference curves for longfinned eel. The graphs on the left show the frequency distribution of the habitats which were sampled (dashed line) and the frequency distribution of the habitats in which the fish were found (dotted line). The graphs on the right show the habitat preference curves.



Longfinned eel

Figure 2 — continued



Longfinned eel

Figure 2 — continued

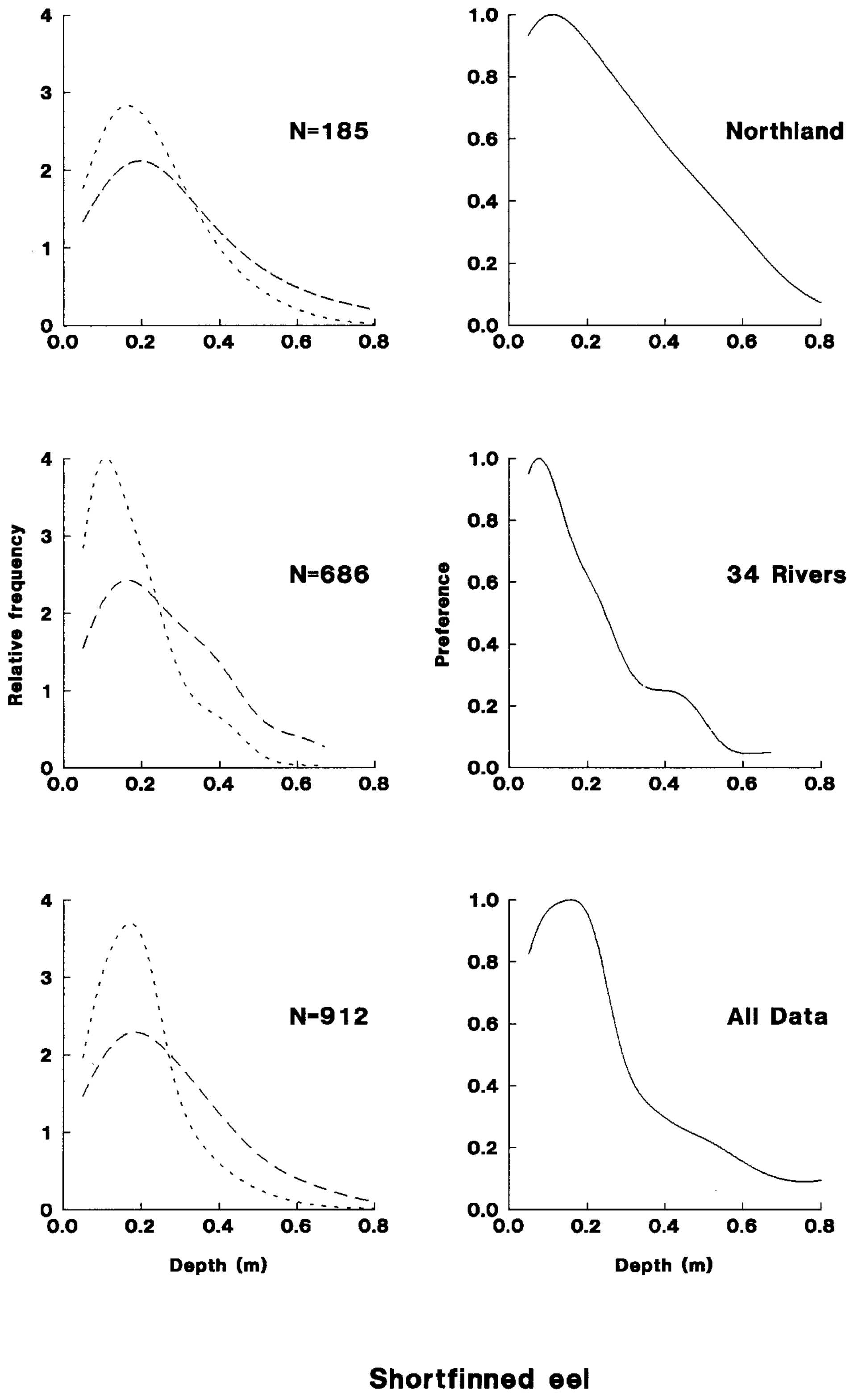
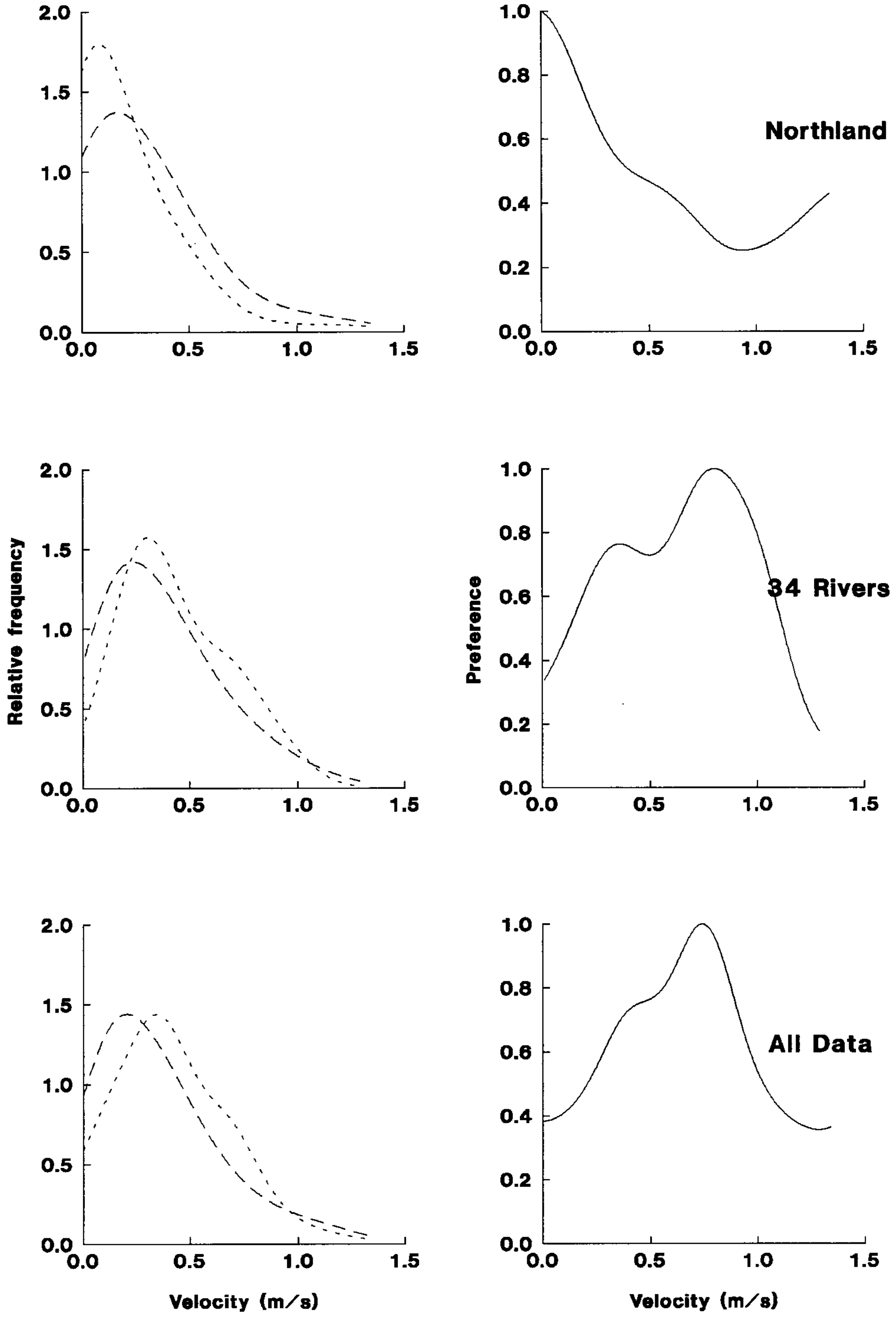
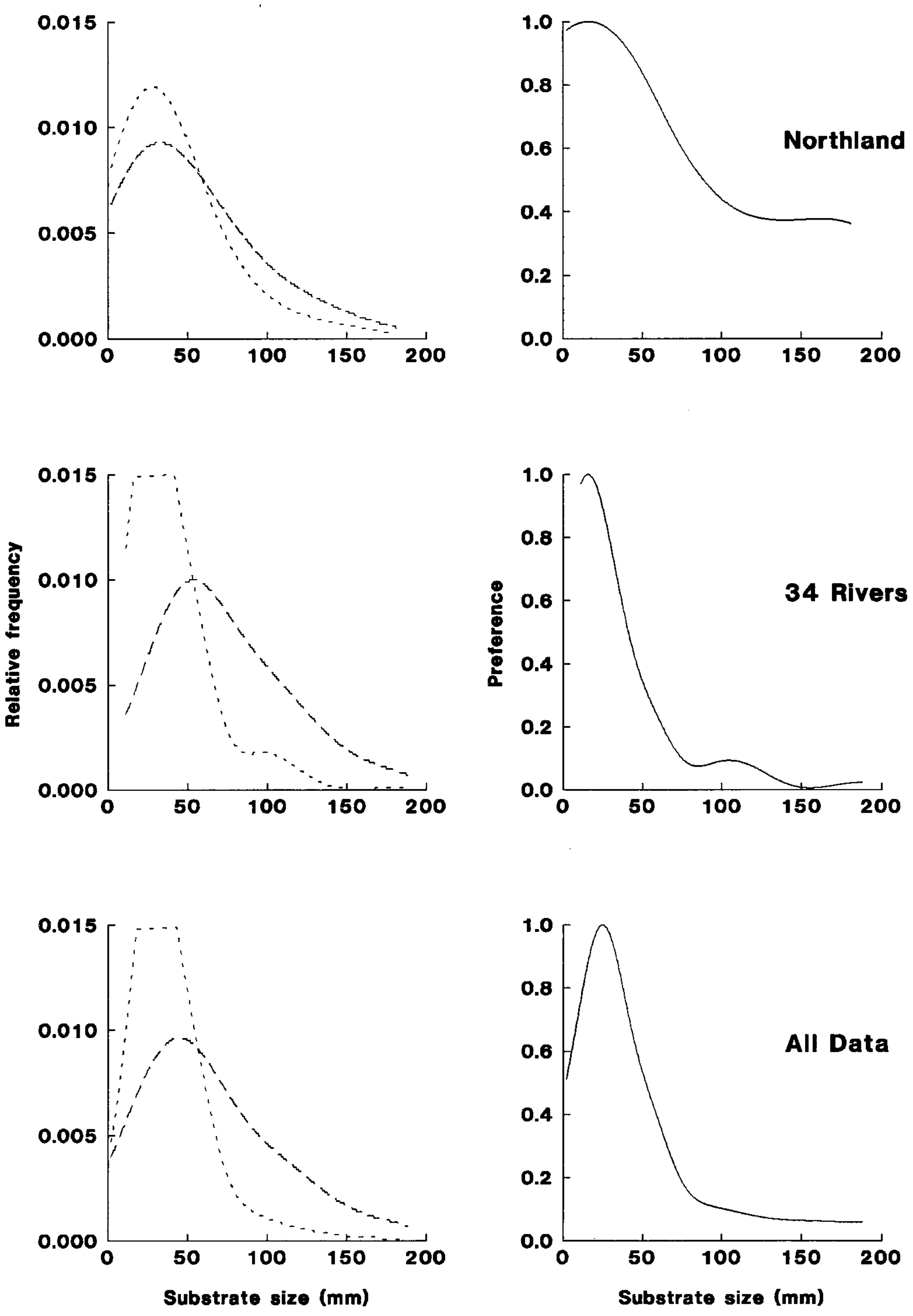


Figure 3: Depth, velocity, and substrate habitat preference curves for shortfinned eel. The graphs on the left show the frequency distribution of the habitats which were sampled (dashed line) and the frequency distribution of the habitats in which the fish were found (dotted line). The graphs on the right show the habitat preference curves.



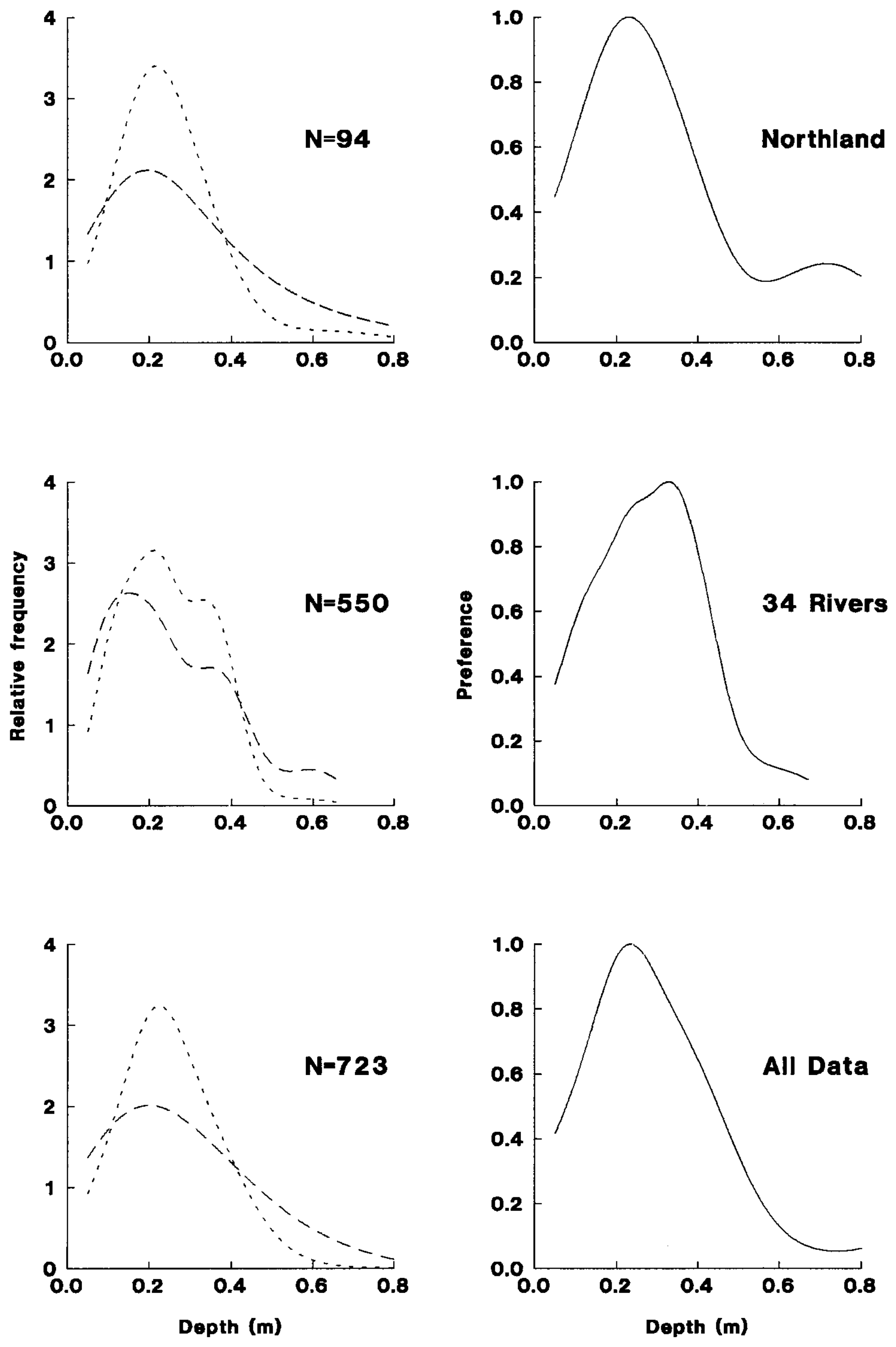
Shortfinned eel

Figure 3 — continued



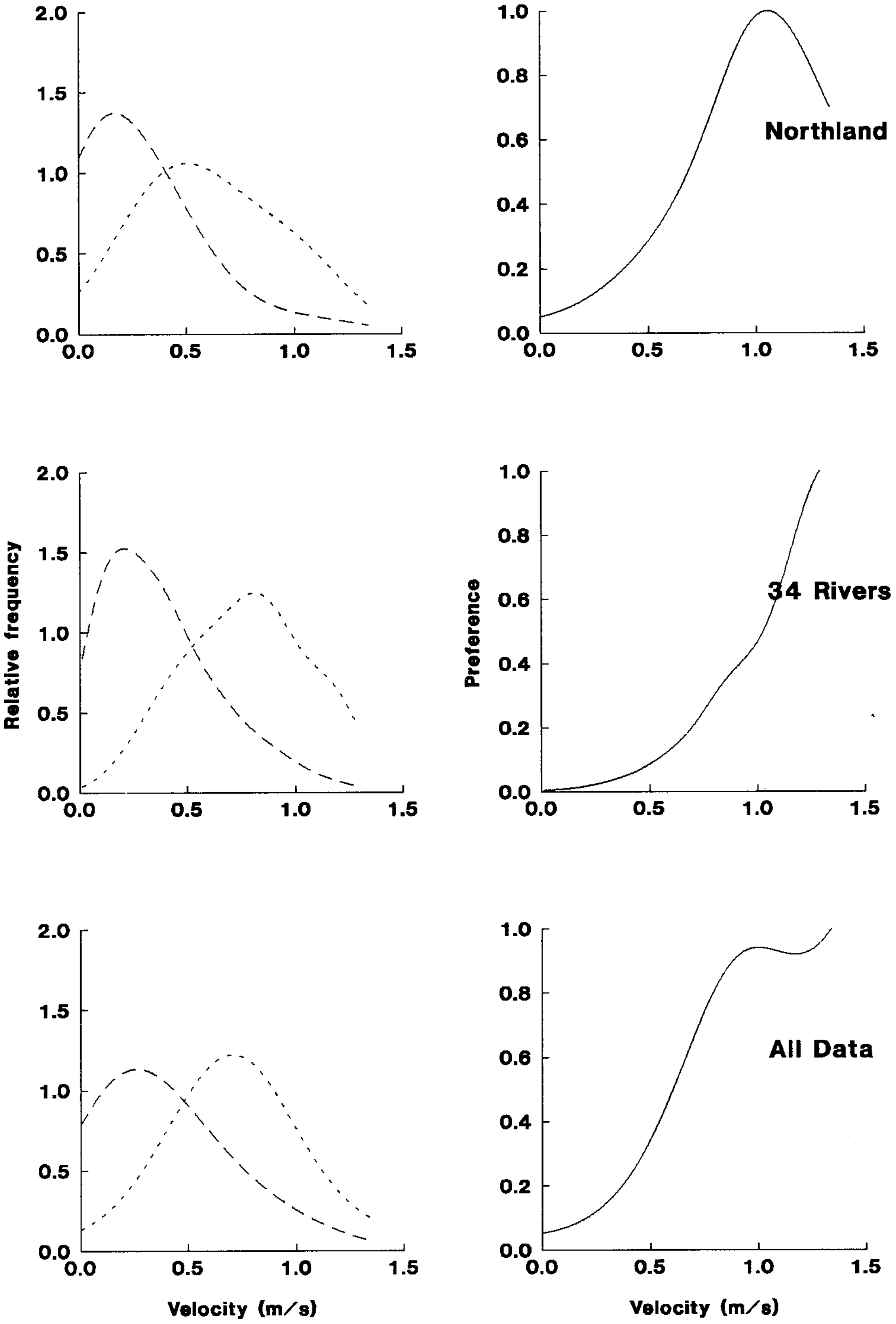
Shortfinned eel

Figure 3 — continued



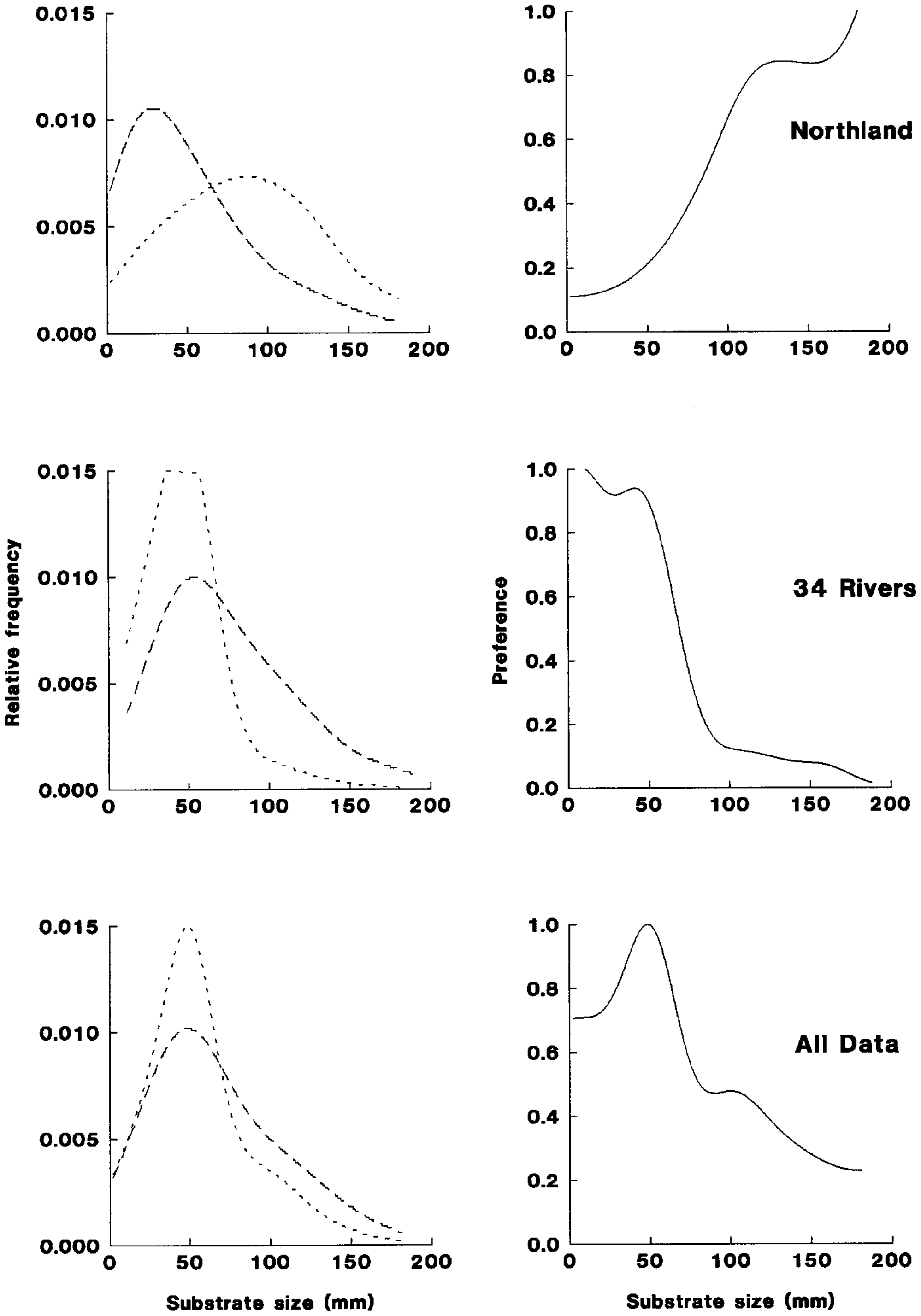
Torrentfish

Figure 4: Depth, velocity, and substrate habitat preference curves for torrentfish. The graphs on the left show the frequency distribution of the habitats which were sampled (dashed line) and the frequency distribution of the habitats in which the fish were found (dotted line). The graphs on the right show the habitat preference curves.



Torrentfish

Figure 4 — continued



Torrentfish

Figure 4 — continued

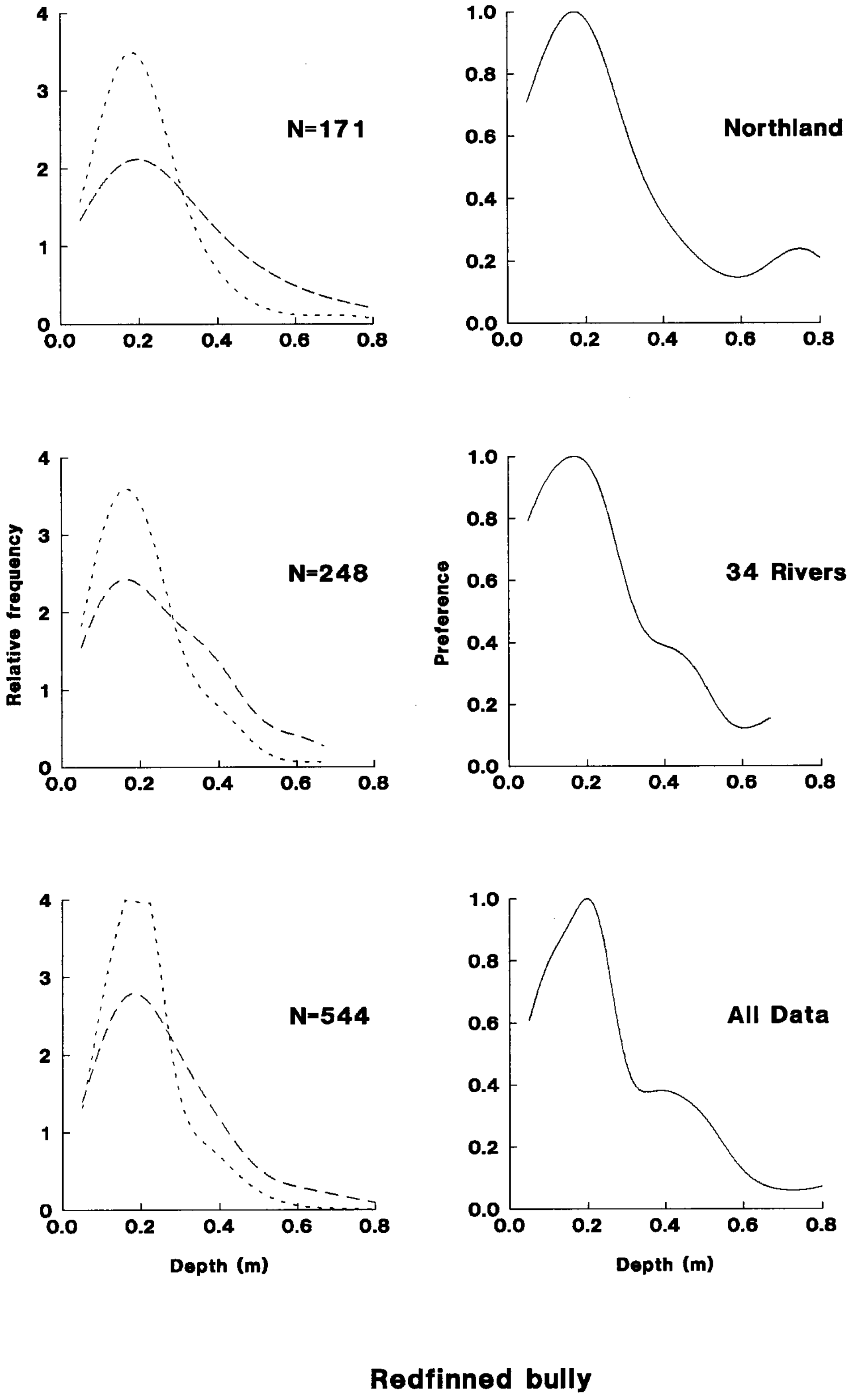
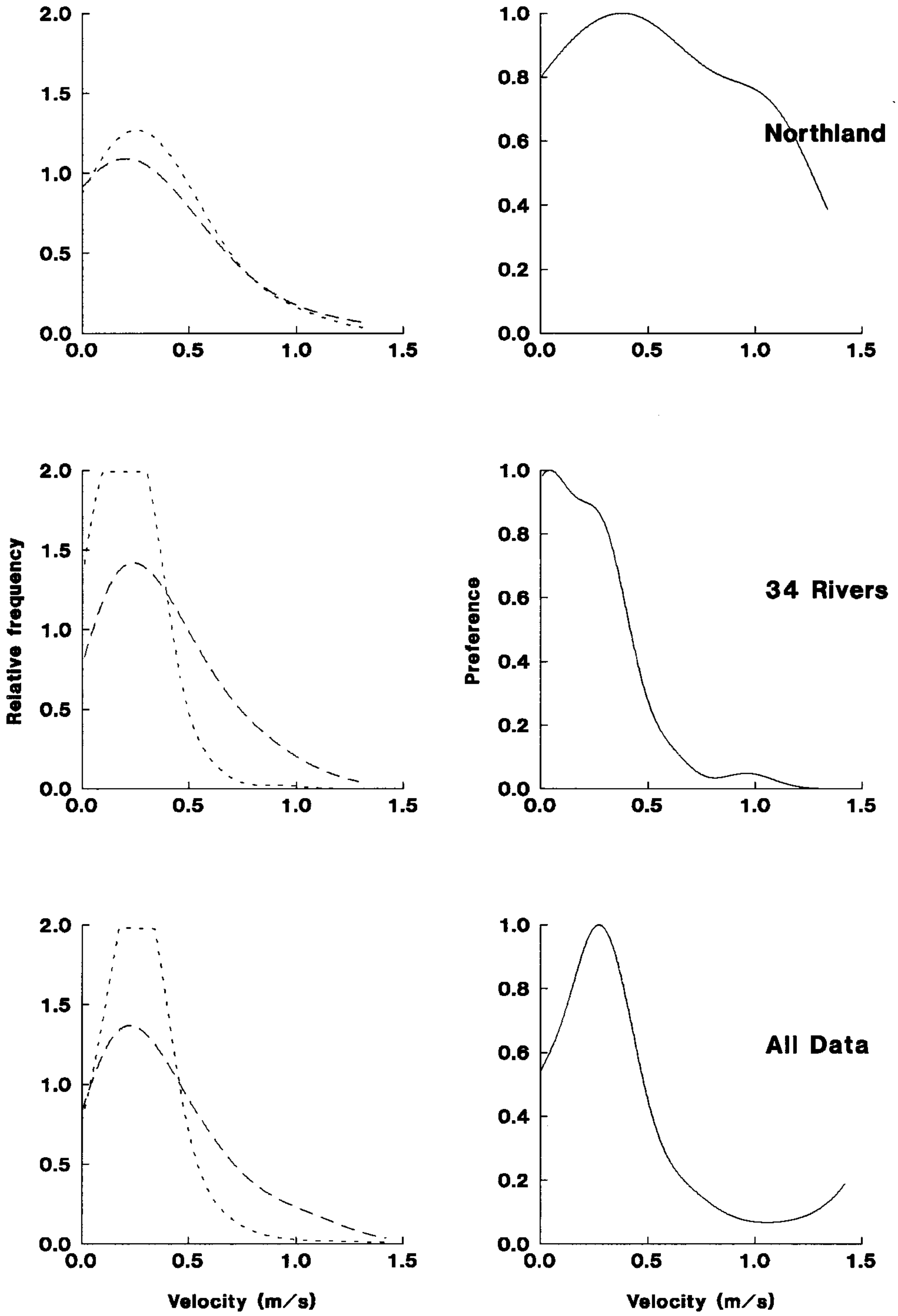
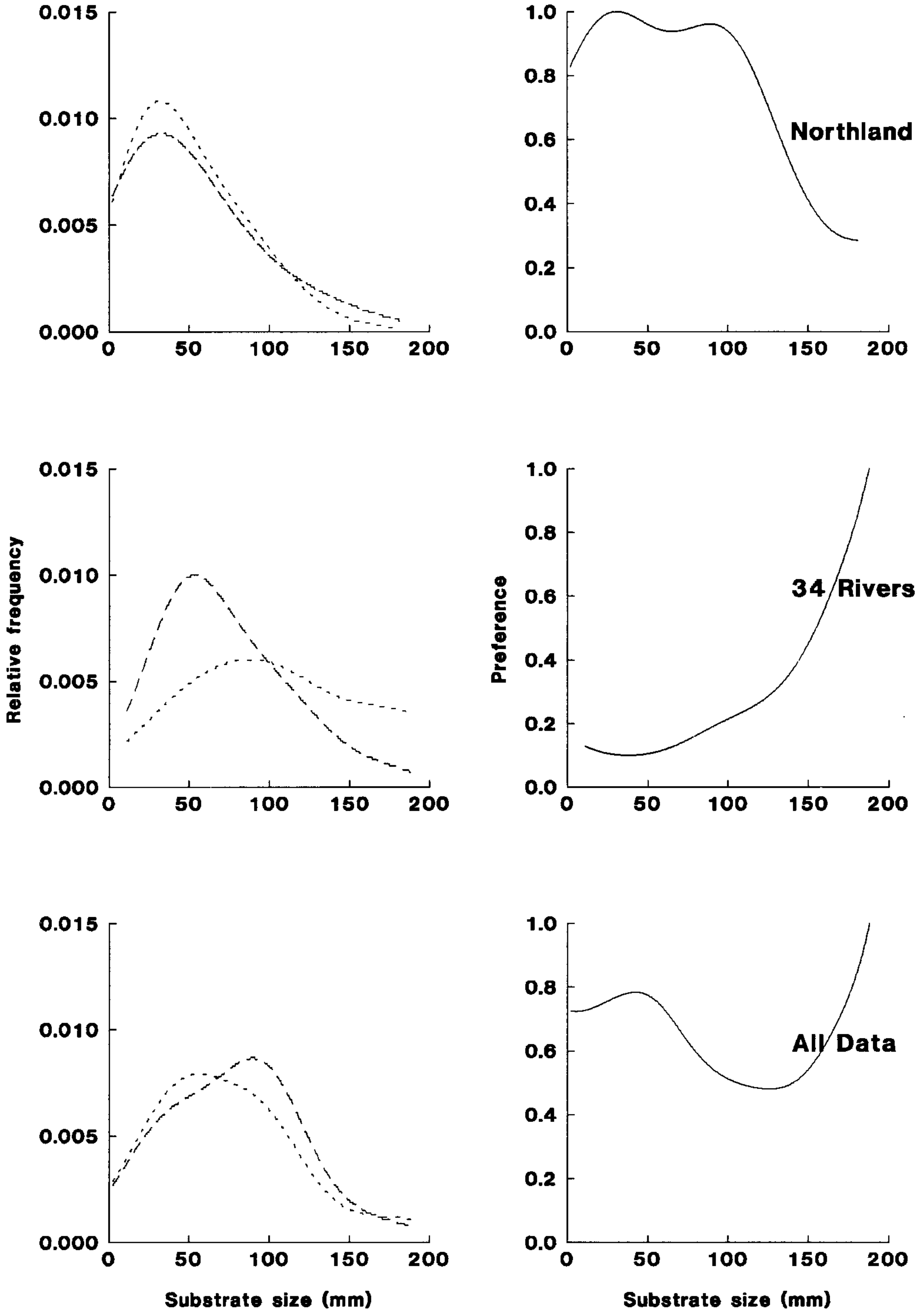


Figure 5: Depth, velocity, and substrate habitat preference curves for redfinned bully. The graphs on the left show the frequency distribution of the habitats which were sampled (dashed line) and the frequency distribution of the habitats in which the fish were found (dotted line). The graphs on the right show the habitat preference curves.



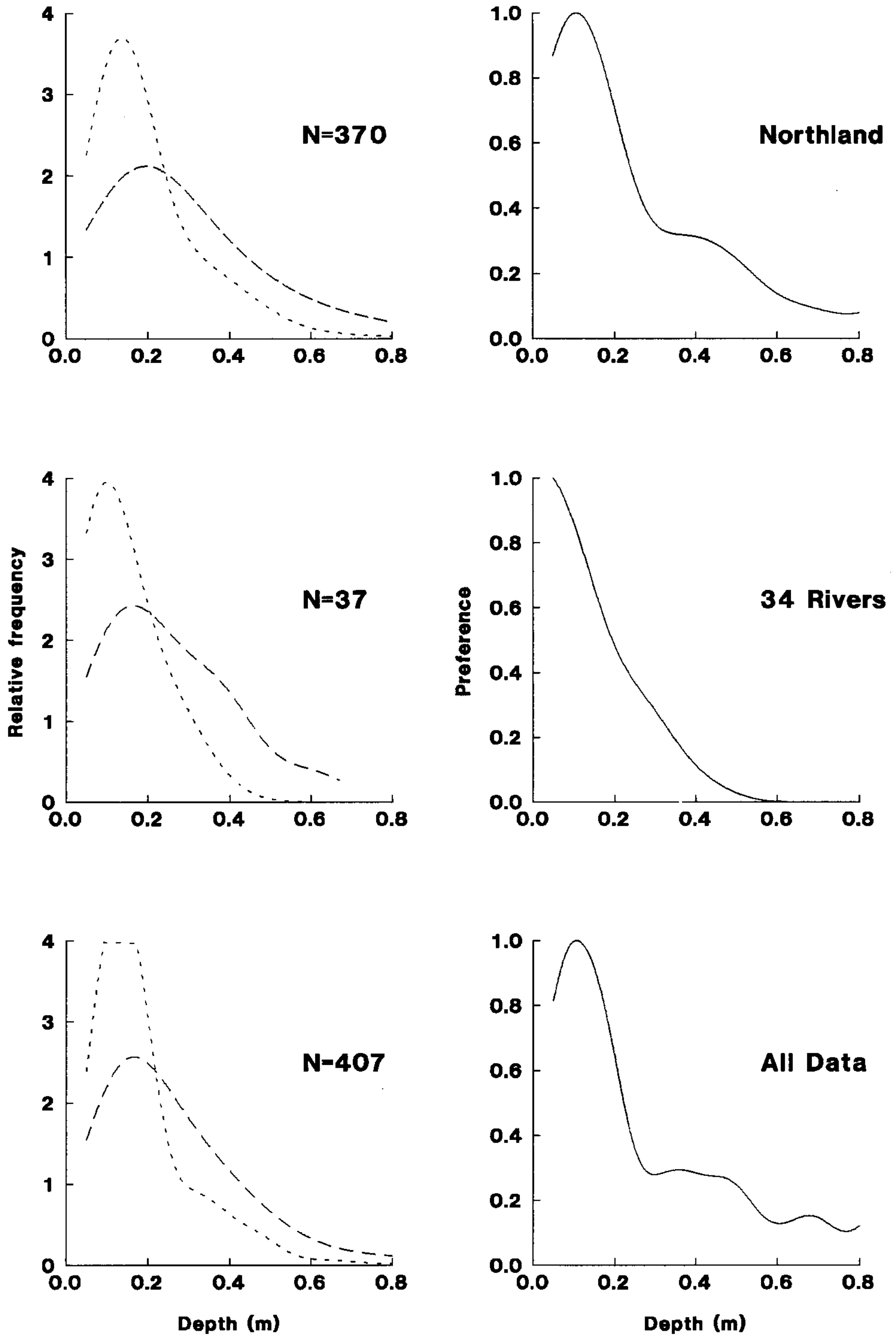
Redfinned bully

Figure 5 — continued



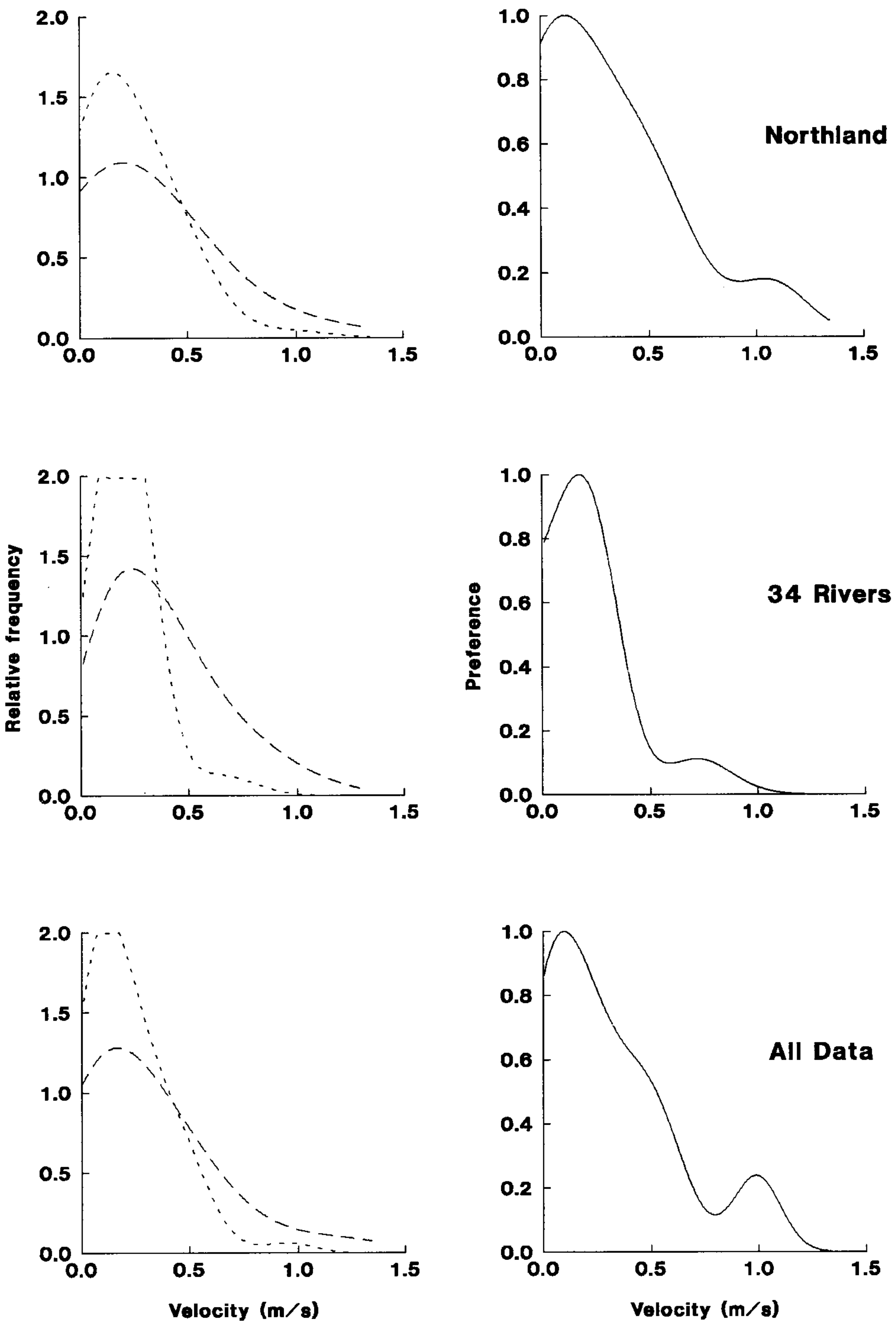
Redfinned bully

Figure 5 — continued



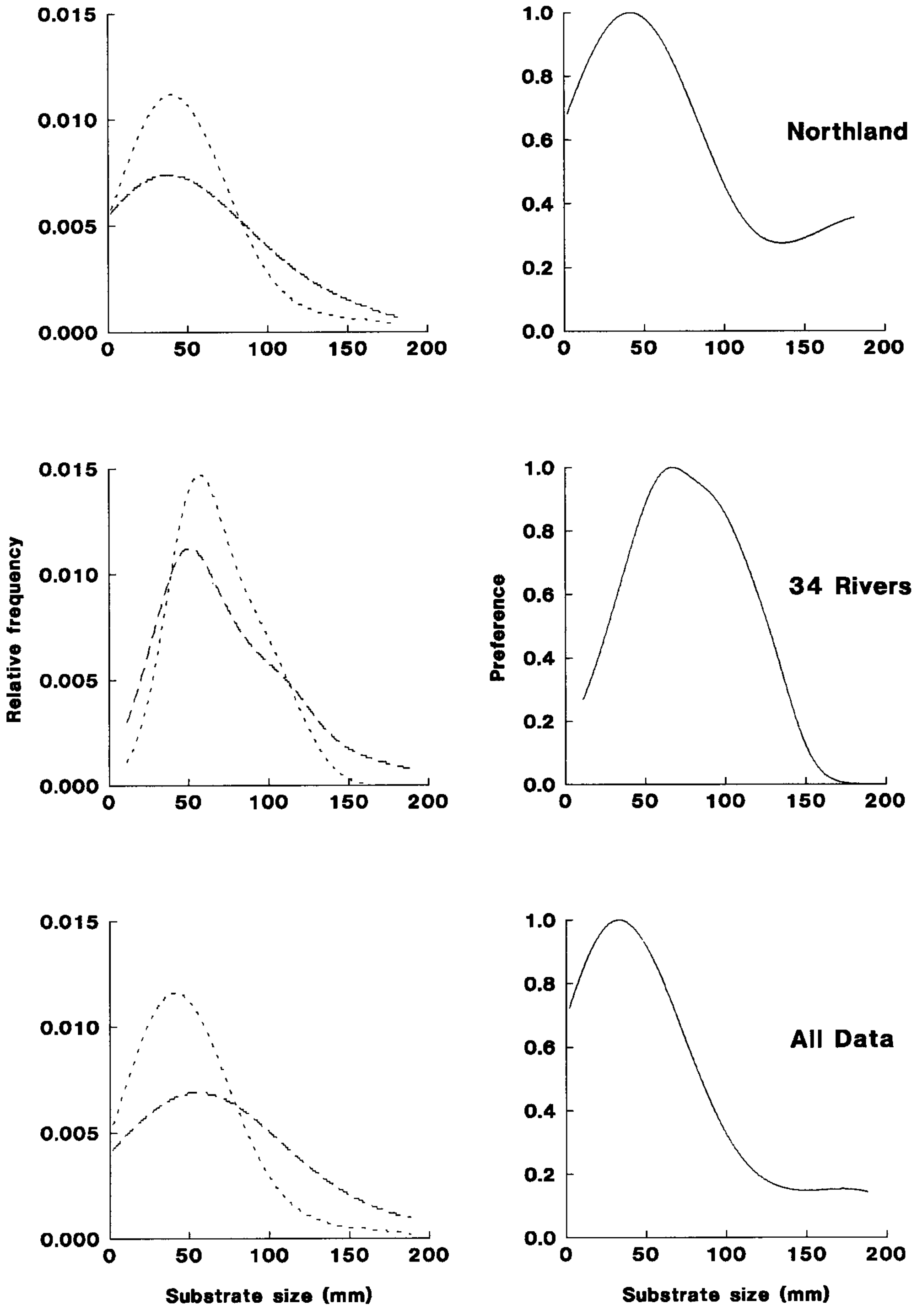
Crans bully

Figure 6: Depth, velocity, and substrate habitat preference curves for Cran's bully. The graphs on the left show the frequency distribution of the habitats which were sampled (dashed line) and the frequency distribution of the habitats in which the fish were found (dotted line). The graphs on the right show the habitat preference curves.



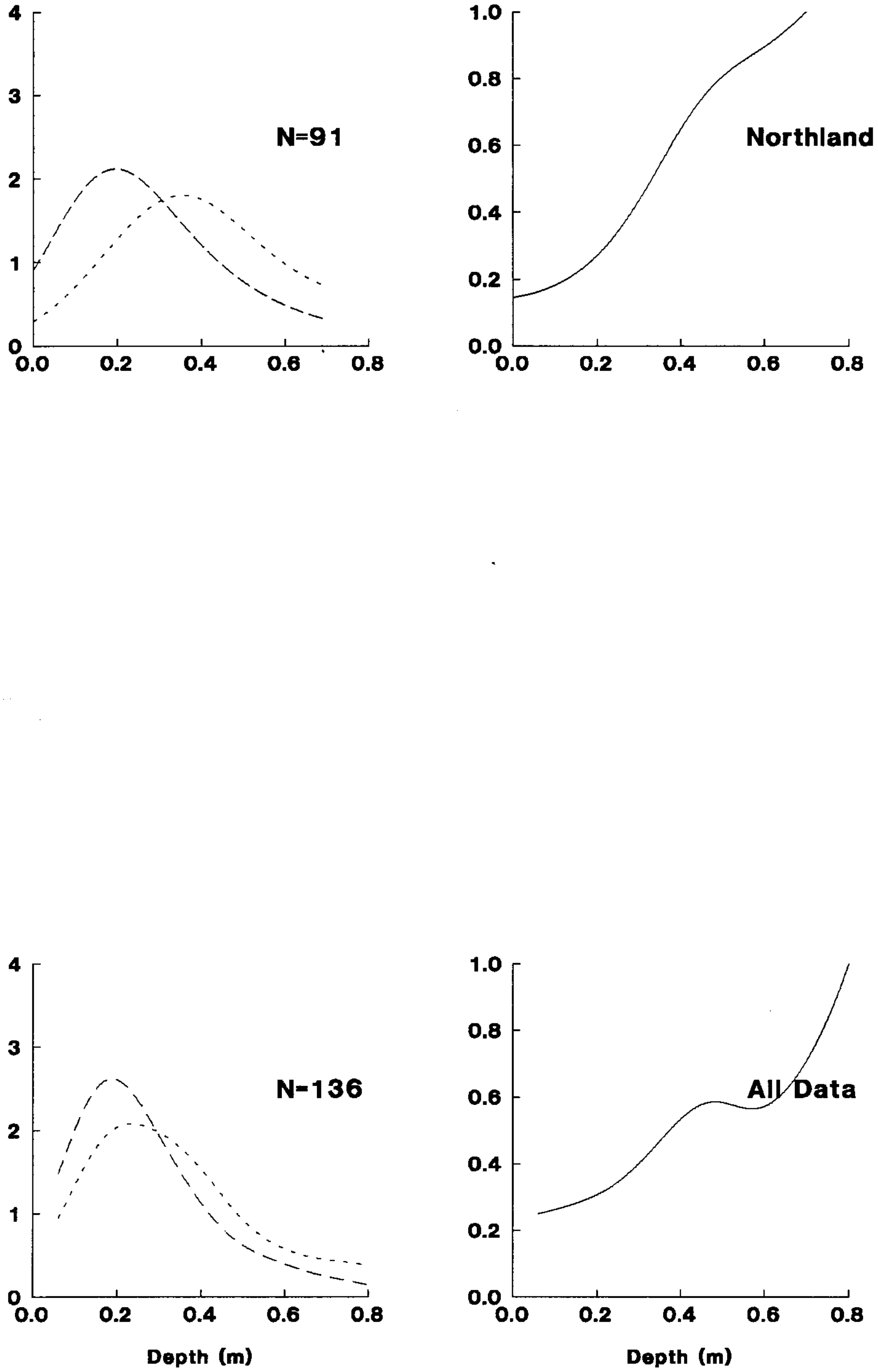
Crans bully

Figure 6 — continued



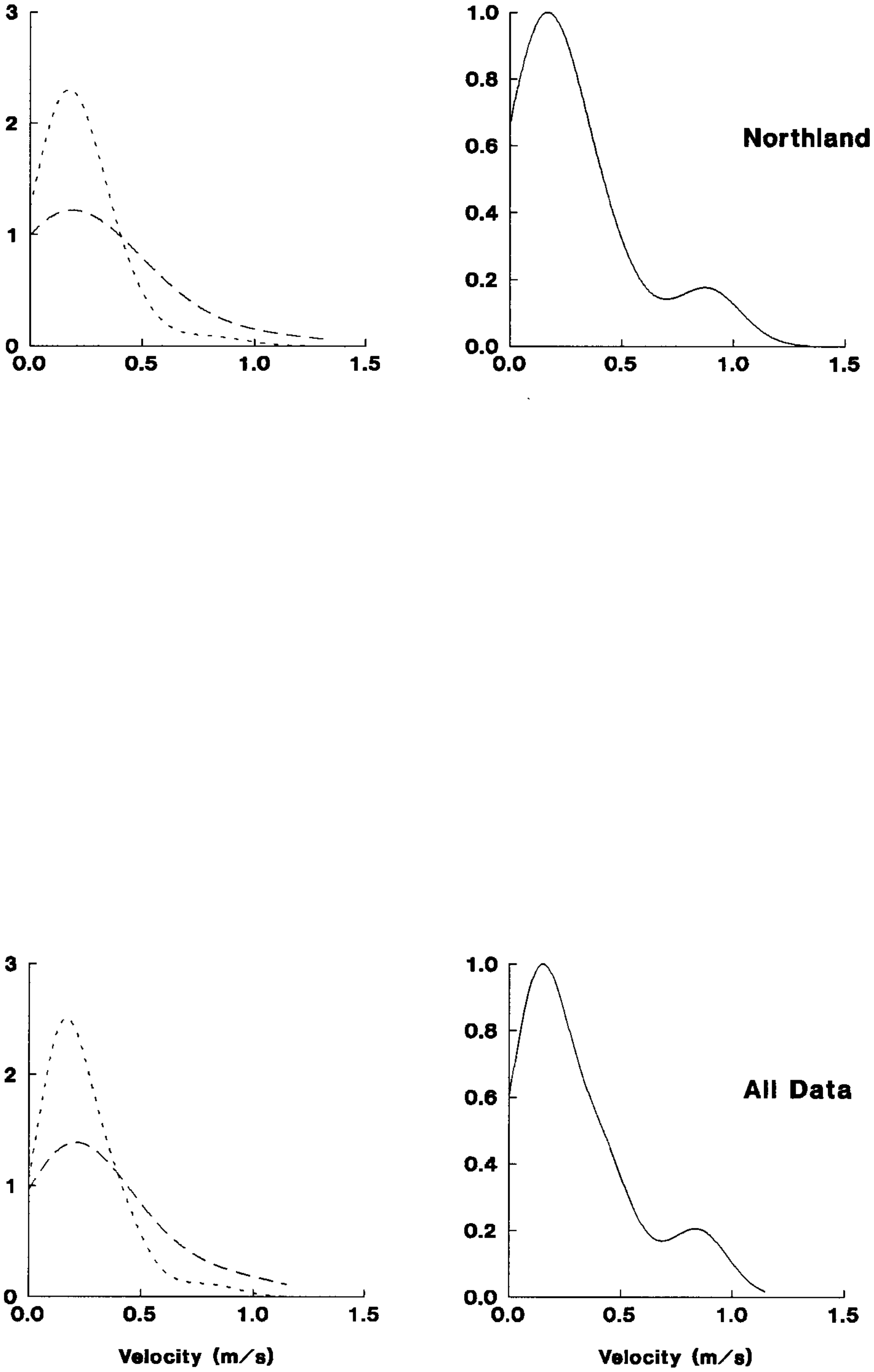
Crans bully

Figure 6 — continued



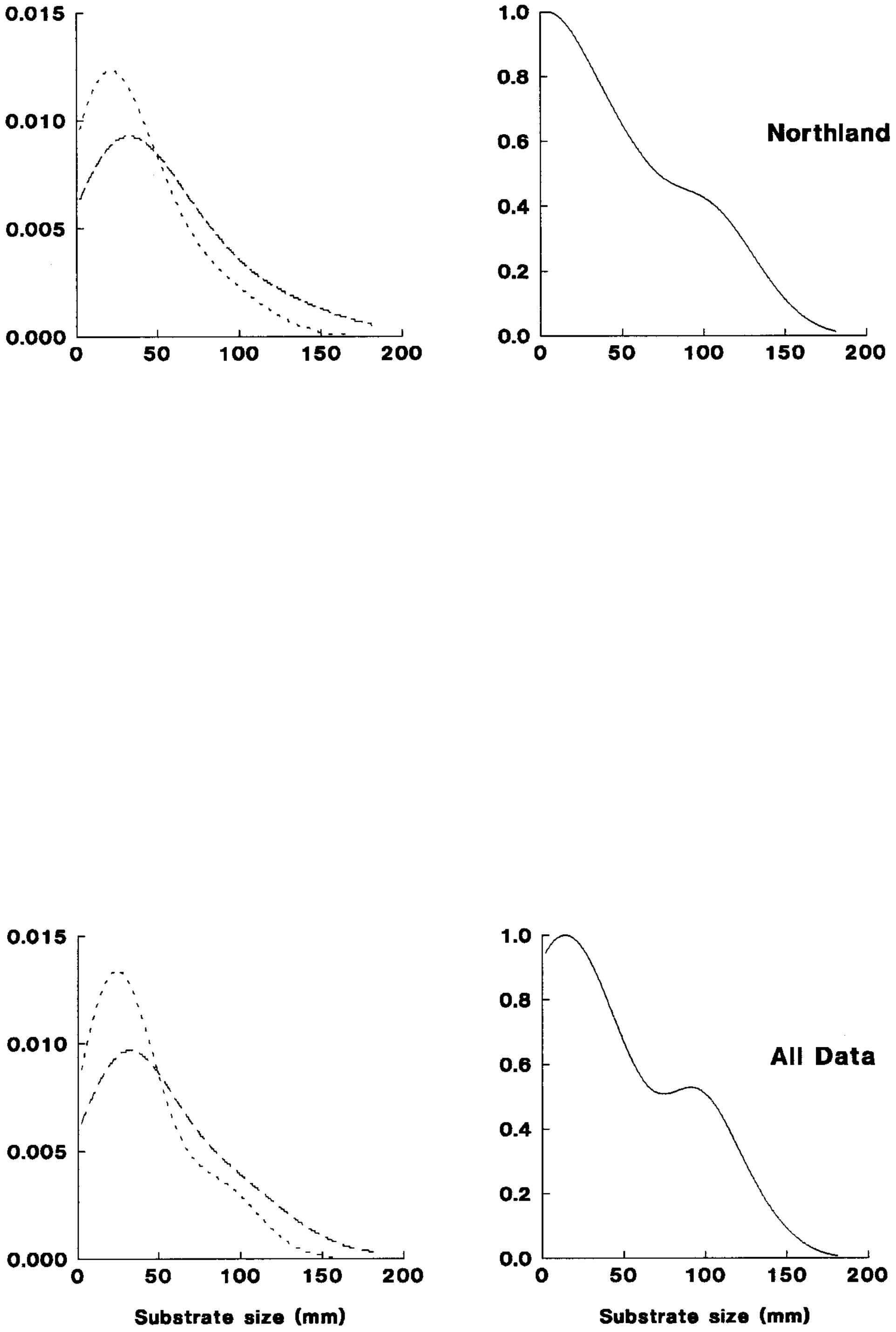
Common smelt

Figure 7: Depth, velocity, and substrate habitat preference curves for common smelt. The graphs on the left show the frequency distribution of the habitats which were sampled (dashed line) and the frequency distribution of the habitats in which the fish were found (dotted line). The graphs on the right show the habitat preference curves.



Common smelt

Figure 7 — continued



Common smelt

Figure 7 — continued

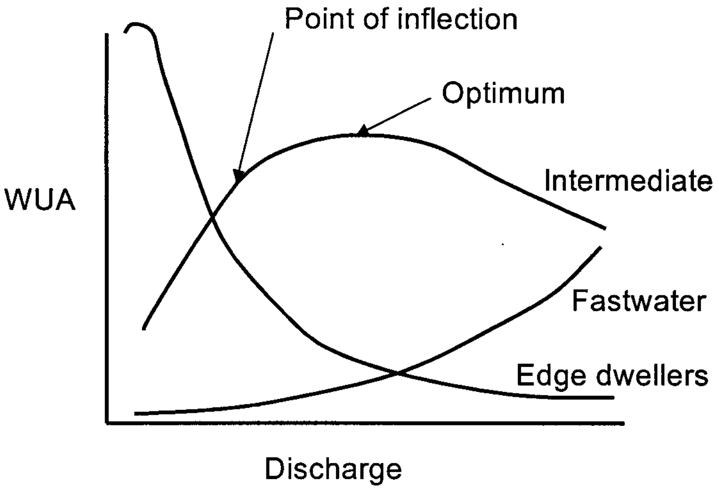


***Figure 8*: Example of variation of weighted usable area (WUA) with discharge for native fish habitat guilds, showing the optimum value and a point of inflection below which habitat drops sharply towards zero.**