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Spring salmon enhancement on the Delphi Fishery, Ireland.

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Abstract

This paper summarises the results of an Atlantic salmon (*Salmo salar*) enhancement programme on the Delphi Fishery in the west of Ireland between 1991 and 1995. The aim of the programme was to increase salmon rod catches in the wake of a sea trout stock collapse. Smolts from two other Irish rivers, Burrishoole and Corrib, were released alongside Delphi fish and differentially tagged.

Record angling catches were subsequently recorded. Catch rates varied from 0.6 to 12.7 per 1,000 smolts released. The comparative performance of the different stocks is assessed, with significant differences emerging between the stocks and between year classes in terms of survival/exploitation rates, run times, sex ratios and homing patterns.

The Delphi fish produced consistently lower overall returns than the Burrishoole groups, but consistently much higher numbers of early-running multi-sea-winter (MSW) salmon. These MSW salmon were predominantly female, while Delphi grilse were predominantly male. The Corrib fish performed relatively poorly. The smaller MSW salmon component of the non-indigenous groups ran later in the season than their Delphi counterparts.

Important size differences in adult returns were noted and related to stock, sex, husbandry and selection by interceptory fisheries. It is suggested that the MSW salmon component of Delphi stocks is attributable to genetic factors, possibly linked to low freshwater temperature regimes.

The programme has contributed to an increase in estuarine draft netting. Exploitation of grilse by all forms of coastal net ranged from 56% to 87%. Exploitation of MSW salmon by nets was lower, ranging from 0% to 54%, the lowest rates being achieved by the early-running Delphi MSW salmon.

The programme is expensive and cannot be justified in terms of direct angling revenue. But when related accommodation income is taken into account, the financial results and the sustainment of the fishery's capital value broadly justify the programme to date.

Terminology

Unless otherwise indicated, the term "salmon" is used generically in this paper to encompass both multi-sea-winter (MSW) salmon and grilse or one-sea-winter salmon. Distinction is also drawn between "early-running" MSW salmon, popularly known as spring salmon which generally enter rivers before mid-May, and "late-running" MSW salmon, popularly known as summer salmon, being those that run in after mid-May.

Introduction

The Delphi Fishery is located in County Mayo on the western seaboard of Ireland **(Fig.1)**. It drains a mountainous catchment of some 52 Km^2. The system includes a chain of three angling lakes, Glencullin Lough (54 ha.), Doolough (304 ha.) and Finlough (28 ha.), discharging to the sea via the Bundorragha River (2.6km) **(Fig. 2)**.

Delphi has been well known to anglers since the early 19th century. Though best known for its sea trout, the fishery also produces salmon. Prior to 1986, when ownership of the fishery changed hands, Delphi produced average rod catches of less than 50 salmon and around 1,000 sea trout a year.

The angling season opens on February 1 and closes on September 30. Most salmon angling is by fly only, though some early season spinning/trolling is permitted on Doolough. Traditionally, salmon angling has concentrated on the Bundorragha, Doolough and Finlough, in descending order of importance.

Multi-sea-winter (MSW) salmon may be caught from February on. Grilse (one-sea-winter fish) are taken from late May on. Such early runs of MSW salmon are rare in this part of Ireland (*Went, 1970*).

Delphi shares its estuary with the Erriff River, a 13km spate river producing rod catches of up to 800 salmon a year. Though many of the Erriff's spawning streams rise in the same mountains as those of Delphi, catches of MSW salmon prior to late May on the Erriff are rare and the great majority of all salmon caught are grilse (*J Stafford, pers. comm.*).

The estuary for both systems is Killary Harbour, a narrow fjiord, 15kms long, the topography, hydrology and geology of which have been described elsewhere (*Keegan & Mercer, 1986*). Salmon are exploited commercially in the estuary by up to 12 netting crews using draft nets (a form of shore-based haul net extended by canvas boat). Since the late 1960s the netsmen have mostly concentrated on the grilse runs from late May, even though the legal draft netting season opens on February 16 (and closes in late July).

There is also an extensive drift net fishery along the coast outside Killary Harbour, as there is all round the Irish coastline. The drift net fishery generally opens on April 1 and closes in late July. In many locations, however, the drift net fishery rarely operates before late May.

Rod catches of wild salmon and sea trout from 1985 to 1995 are shown in **Fig. 3.**

The serious drop in sea trout catches in 1987/88, culminating in the stock collapse of 1989/90 (*Whelan et al., 1993*), prompted a major review of the rod fishery operation. After extensive consultations in the summer of 1990, notably with the Salmon Research Agency and the Department of Marine, Delphi's management decided to try to increase salmon runs, particularly in the summer months, to preserve fishing credibility.

Methods

It was decided to construct a 50,000-smolt hatchery with the aim of increasing average rod catches of salmon to around 200 per annum, the minimum considered necessary to attract substantial angling interest. The size of the hatchery was based on estimates at the time which suggested that on average 2% of smolts would return to Delphi, of which around 10% would be caught by anglers. Thus salmon catches should increase by 2 for every 1,000 smolts released so that, on average, a 50,000 smolt release would produce an extra 100 salmon to the rod.

The hatchery cost approximately IR£75,000 (US$112,000) to construct, with annual running costs, excluding depreciation, of approximately IR£40,000 (US$60,000). The hatchery employs one full-time person and up to five others when required.

Before the salmon enhancement programme was fully initiated, baseline studies of juvenile salmonid densities were conducted. Samples of genetic material were also taken from both wild and hatchery juvenile stocks by the Salmon Research Agency *(Anon., 1994 a)*.

The decision to rear and release smolts, rather than fry or parr, was motivated by a desire to protect wild juvenile populations and to circumvent the naturally limited nursery habitat of the Delphi system. It was also recognised that higher egg-to-smolt survival rates could be achieved than in the wild, and higher egg-to-adult return rates were probable for smolts as opposed to parr or fry.

Only one-year-old smolts (S1s) were used in the programme because of fears that S2s would be more prone to disease in the hatchery.

Increased smolt predation, particularly by cormorants, was anticipated and counter-measures put in place.

It was decided initially to import smolts from two other local salmon stocks - those of the Burrishoole and Corrib systems - for release alongside the progeny of Delphi's indigenous wild fish. These two stocks were chosen for their geographic proximity and their proven success as "ranching" stocks. There was a desire to verify that the Delphi stock could perform as well as the others.

Subsequently, it was decided also to import ova from these other stocks for ongrowing in the Delphi hatchery in order to see if this affected performance and straying rates.

A separate study was initiated to compare the performance of Burrishoole fish released at Burrishoole with the Delphi releases of Burrishoole smolts and ongrown ova. This has since been completed *(Rogan, 1996)*.

The location of the hatchery and the smolt release point in Finlough were both chosen so as to maximise the scope for segregating wild and reared stocks and for ultimately removing reared adults, thereby preventing them from spawning or interbreeding with the wild fish. It was also hoped that, by homing to Finlough, the reared fish would particularly benefit angling in that lake and in the river, the areas considered most suitable for flyfishing.

The Burrishoole and Corrib smolts were brought to Delphi at least 8 weeks before release so as to imprint them with the Delphi chemistry. Previous work had shown this to be a sufficient time period to achieve subsequent homing to the release location

(McDermott, 1990). All release groups had their adipose fins clipped and were differentially tagged, using coded wire nose implants (a technique described by *Bergman et al., 1968*).

Small numbers of Delphi parr and smolts, also clipped and tagged, had been released in 1989 and 1990, prior to the start of the main enhancement programme. In 1991, larger groups of Delphi, Corrib and Burrishoole smolts were released. In 1992, a fourth group, derived from Corrib eggs reared at Delphi, was also released. In 1993, no Corrib stocks were used and a group raised at Delphi from Burrishoole ova was released alongside a Delphi group. The numbers of fish released in each group are shown in **Table 1.**

Details of the broodstock which produced the imported smolts and ova are not fully known, although the Corrib-egg group was specifically requested to be the progeny of MSW salmon. It is believed that the great majority of all other imported groups derived from predominantly grilse parentage. Details of the Delphi broodstock used in each year are shown in **Table 2.**

Tags from returning adult salmon were subsequently recovered from offshore drift nets (*Anon., 1991, 1992, 1993, 1994 b*), estuary draft nets, rod catches and post-season trapping within the Delphi system. For tag recoveries from within the Killary/Delphi system, the length, weight, sex and other characteristics of the fish were recorded and genetic material was taken to assist other studies.

Tag recovery rates for each group were engrossed by raising factors to establish the survival-to-catch rate (STC), which is the survival implied by the total exploitation (all methods - offshore, estuarine and in-system). The STC is expressed in terms of the number per 1,000 smolts released. The raising factors applied to estuary and drift net catches are estimates of total netted populations based on sample inspections of local and national commercial catches. In addition, drift net catches were further raised to incorporate Department of Marine estimates of unreported net catches and other coastal mortality factors for adult salmon, collectively known as the "NCFM factor" or non-catch fish mortality.

Survival to the river and rates of escapement to spawn were then calculated using estimated rod exploitation rates (15% for grilse, 25% for MSW salmon).

Home-water-survival (HWS), being the rate of return to Irish coastal waters, was also established for each smolt group, using the same raising factors for drift and draft net catches but also including escapement estimates.

MSW salmon-to-grilse ratios were also calculated for each cohort of both wild and reared Delphi smolts, expressed as the percentage of MSW salmon in the total MSW salmon/grilse population for each group.

Results

The smolt release programme at Delphi resulted in significantly increased rod catches of adult salmon **(Fig. 4, Table 3).** Catches of MSW salmon and grilse from 1986 to 1995, including reared fish, are shown in **Fig 5.**

Seven out of the ten smolt groups released between 1990 and 1993 produced rod catch rates in excess of the 2 per 1,000 target **(Table 4).** The lowest catch rate was 0.6 per 1,000 smolts (the 1992 Corrib smolt release) and the highest catch rate was 12.7 per 1,000 (the 1993 Burrishoole group). The relatively poor performance of all

Corrib groups, which produced three of the four lowest catch rates experienced over the four years, led to the eventual dropping of Corrib fish from the programme.

The rod catch rate of the Burrishoole groups was consistently higher than the other groups, ranging from 4.7 to 12.7 per 1,000 smolts, as compared to 1.9 - 5.7 for Delphi and 0.6 - 2.2 for the Corrib groups.

The Delphi groups, however, produced much higher rod catches of MSW salmon than the other groups, ranging from 1.5 to 4.1 per 1,000 smolts, as compared with 0.3 - 0.9 for Burrishoole groups and just 0.1 to 0.7 for Corrib groups.

In contrast, the Delphi groups were relatively poor producers of grilse to the rod, with catch rates ranging from 0.2 to 3.4 per 1,000 smolts. Burrishoole groups, however, produced grilse rod catch rates as high as 12.4, while Corrib groups never exceeded 1.5 per 1,000.

The tendency of the Delphi groups to produce MSW salmon is reflected most strongly in the rod catches, with 49% of all reared Delphi fish taken by rods over the four years being MSW salmon.

Between 1992 and 1995, 50% of all reared fish taken by Delphi anglers were caught in the Bundorragha River, almost exactly matching the proportion of wild salmon taken in the river **(Fig 6)**. In contrast, 46% of reared fish were caught in Finlough, as opposed to only 19% of the wild fish. In 1994, 212 salmon were caught on Finlough, 177 or 83% of which were reared, as compared to a total catch for that lake in 1991 of only 5 wild fish. Management's hopes for boosting Finlough angling and for segregating reared from wild fish were therefore achieved to a notable extent.

Conversely, Doolough, which is upstream of both the hatchery and the smolt release point and closer to many of the primary spawning grounds, delivered only 4% of the reared fish rod catch but 29% of the wild salmon catch. Of these reared fish caught in Doolough, 67% were of Delphi origin - even though only 44% of all reared fish caught in the system as a whole were Delphi. Thus, the indigenous groups had a greater tendency to overshoot Finlough than the non-indigenous fish.

Homing into the Delphi system was high for all groups, with lower straying rates in Delphi groups than in the non-indigenous stocks **(Table 4)**. The highest straying rate was 5.3 per 1,000 smolts, derived from the 1991 release of Burrishoole smolts which returned as grilse in the dry summer of 1992 and some of which entered the larger Erriff River nearby. Rates of straying by MSW salmon were negligible.

The relative overall performance of the different groups, expressed in terms of survival-to-catch rates (STC), broadly mirrored the rod catch rates. The Delphi groups, however, recorded progressively higher STC rates over the four years (rising from 6.4 to 74.8 per 1,000 smolts released), while the STC rates of the Delphi MSW salmon component rose from 2.6 to 8.4 per 1,000.

The lowest STC rates of all groups were those recorded by the Delphi parr releases in 1989 and 1990 of 2.1 and 3.4 respectively, in contrast to the Burrishoole smolt groups which achieved STC rates of up to 147.4 per 1,000 and never lower than 96.7.

Similarly, home-water-survival (HWS) of Burrishoole groups as grilse was consistently higher than the other stocks and consistently over 100 per 1,000 smolts released **(Table 5)**. The HWS rate of Delphi groups as grilse was invariably lower than that of other groups, with the exception of the 1992 Corrib-egg group (which derived from

MSW salmon parentage). However, the HWS of the Delphi groups as MSW salmon was consistently 4 to 6 times higher than the Burrishoole MSW salmon groups.

Survival to the rivermouth (RS) of Delphi MSW salmon was higher than for Delphi grilse from the same cohort for all release years except 1993 **(Table 5).** Delphi's MSW salmon were predominantly early-running, whereas the few Corrib and Burrishoole MSW salmon were predominantly late-running **(Fig. 7).** Since early-running fish may avoid much of the commercial netting effort, the Delphi stocks have a natural advantage.

Exploitation of Delphi MSW salmon by drift nets was comparatively low, ranging from zero to 16% of those returning to the Irish coast. This is four to 10 times lower than for all other groups of MSW salmon except one Corrib group. However, draft net exploitation of Delphi MSW salmon is increasing, from zero in the 1992 and 1993 netting seasons to 15% of home water survivors in 1994 and 25% in 1995 **(Table 5, Fig. 8).** Some draft net crews are now operating in March and April for the first time in many years *(S Nixon, pers. comm)*.

The increase in draft net catches was particularly significant in summers with low rainfall such as 1992 *(Anon., 1995)* when exploitation of grilse by draft nets exceeded 31% of all home water survivors respectively.

Exploitation by nets (all types) of grilse groups was always higher than for MSW salmon groups. Net exploitation rates fluctuated from year to year but were never less than 50% of home water surviving grilse and reached a maximum of 87% of Corrib grilse in both the 1992 and 1993 netting seasons.

Almost 98% of the Burrishoole fish caught by all methods during the programme period were grilse, compared to 91% of Corrib and only 83% of Delphi fish **(Table 6).** In all, 4,103 tags were recoved from the 123,082 tagged smolts and parr released between 1989 and 1993, a recovery rate of 3.33%.

The grilse caught in the drift net fishery were larger than the survivors to the estuary for all groups except one **(Table 7).** There appears to be a relationship between smolt size and resulting grilse size **(Table 8).** However, of the four smolts groups released in 1992, the smallest smolts in terms of length and weight (the Corrib-egg group) produced the largest grilse (and then the smallest MSW salmon) **(Table 9).** It was discovered that all of these grilse were male fish, which have been found to be larger than females of the same age *(Went, 1943)*, while all but one of the MSW salmon from the same group were female.

The sex ratios of adult salmon recovered from draft nets and within the Delphi system are shown in **Table 10.** Delphi grilse were predominantly male (75%), while Delphi MSW salmon were mostly female (80%). The sex ratios of Corrib groups varied. Burrishoole MSW salmon were also predominantly female (91%), while the more prolific Burrishoole grilse exhibited a more even 51/49 overall male/female ratio.

Based on ratios derived from rod catches, Delphi reared fish produced proportionately more MSW salmon than their wild counterparts **(Table 11).** This MSW salmon ratio appears to be stable in the wild at between 25% and 48% of rod catches. The high (95%) MSW salmon ratio of the 1991 reared Delphi group included the only two three-sea-winter fish caught on rod.

The sizes of reared Delphi grilse in the rod catch resembled that of wild grilse caught **(Table 12).** The length of wild smolts migrating from Delphi in 1960/61 had previously been estimated at 13.2 cms and a high proportion of smolts in those years were found to have migrated after two or even three years in freshwater. None migrated after just one year *(Went, 1964)*. If this is still true of the wild smolts today, then the hatchery-reared smolts differ from their wild counterparts in both age and size.

Eggs stripped from Delphi MSW salmon were 40% larger than those taken from Delphi grilse in 1993 and 31% larger in 1994.

It is not known how effective the post-season netting of reared fish was at Delphi and thus how many non-indigenous fish survived to spawn. However, population estimates extrapolated from rod catches would indicate that these formed a clear minority of the overall spawning population, consistently less than a third and often much lower. Furthermore, those that did spawn may have done so in discrete areas not used by wild fish. Visual observations revealed extensive spawning activity in the vicinity of the hatchery outflow, an area not normally used by wild stocks. Over the programme period, less than 2% of all fish netted during November/December in Finlough and close to the hatchery were wild. Most of the main wild spawning areas are well upstream of the hatchery, off Doolough and Glencullin Lough.

The programme has revived angling income at Delphi, which had dropped significantly in the wake of the 1989/90 sea trout collapse, and it has contributed to increased accommodation sales at Delphi Lodge **(Table 13)** and to the maintenance of the fishery's capital value.

Discussion

The salmon enhancement programme at Delphi was primarily driven by commercial angling considerations. However, it has had the incidental benefit of providing a large volume of information on:

* The performance of different stocks reared and released under similar conditions
* The potential for enhancing spring salmon
* The impact of commercial netting on Irish rod fisheries

Arguably the most important result of the Delphi programme in the context of this conference is the consistently superior performance, expressed either in terms of rod catches or total catches, of the Delphi groups as MSW salmon, in contrast with the relatively poor MSW salmon returns from other groups. Further, the tendency of the Delphi MSW fish to run in the spring, prior to mid-May, contrasts strongly with the later average run times of other MSW groups.

Prospects for enhancing spring salmon angling would therefore appear to depend not merely on the production of MSW salmon, but particularly of early-running MSW salmon.

The Delphi programme shows that it is possible to significantly enhance spring salmon runs through large scale releases of S1 smolts. This was, however, an accidental result of the programme and it is not entirely clear how it came about. There are nonetheless a number of indications in the data as to what makes a spring salmon and these have been assembled to form a hypothesis as a basis for further analysis and research.

What makes a spring salmon?

The spring salmon component present in the wild Delphi population appears fairly stable, based on rod catches. Other work has shown rod catches to be a reasonably reliable indicator of populations entering a river (*Gudjonsson et al, 1995*). The reared Delphi fish have also consistently produced high proportions of MSW salmon in the rod catches, in fact higher than those of the wild fish. This is perhaps due, as discussed below, to broodstock selection - the highest MSW salmon ratio derived from broodstock with a high MSW content, while the lowest ratio resulted from the use of predominantly grilse broodstock.

In contrast, the Burrishoole ova group, reared under similar conditions and released simultaneously at Delphi, produced few MSW salmon and even fewer early-running or spring salmon. Burrishoole fish released at Burrishoole have tended not to result in many MSW salmon (*Piggins, 1973*). It might therefore be deduced that these reared groups of both Delphi and Burrishoole smolts are broadly mimicking their wild counterparts.

Prior to the advent of intensive drift netting, it was estimated that the size of male salmon was greater than females for all sea age groups and that this size differential increased with age. Further, the proportion of females increased with sea age (*Went 1940*).

MSW salmon returns from all three stocks released at Delphi reveal a predominance of females. Other studies have shown that male salmon tend to be larger and to mature earlier than their female cohorts. The females, it has been suggested, require greater energy accumulation before they can mature (*Crandall & Gall, 1993, b*).

The Delphi programme has shown male MSW salmon to be relatively rare, though present in the highest proportion in the Delphi groups, based on recoveries from the estuary and fishery. In all of the groups of Delphi fish and some of the Corrib groups, the high female ratios in the MSW salmon component were matched conversely by high male ratios in the grilse component of the same groups. This implies that more males than females are maturing in their first year at sea, unless the drift net fishery is selecting females from the population prior to the sex ratio sampling. Given the larger size of males and the fact that the larger mesh size of drift nets selects larger fish (*Twomey, 1980*), it is unlikely that the drift nets are selecting females.

The Delphi results indicate that survival-to-catch rates of MSW salmon vary from year to year. But they also show consistent differences between the performance of the three stocks as MSW salmon in the same year groups, despite similar release sizes. In particular, the surviving female component was not constant between the three stocks. This strongly implies that sex and the slower maturation of females, while relevant, is far from being the sole factor in the production of MSW salmon.

A study comparing spring and summer salmon (early- and late-running MSW salmon respectively) of both sexes found that summer salmon were, on average, considerably smaller than spring salmon of the same smolt class at the end of both the first and second sea winters. Also, incremental growth was greater for the spring fish than the summer fish (*Went 1940*). Spring fish have also been found to be in better condition than summer fish (*Went 1940, Went 1943, Hewetson 1961*).

This suggests that the rates of growth of the different types of salmon - grilse, spring salmon and summer salmon - are not constant, even though larger smolts were found to maintain their relative advantage over smaller smolts as they grew at sea **(Table 8).**

It could therefore be concluded that arrival at the maturity threshold which will produce a spring salmon is a function of growth rate, sex and condition achieved. These factors are in turn under genetic control, interacting with the environment through the relative survival or fitness of different salmon populations.

It is suggested that stocks which survive poor environmental conditions, arising for example from low freshwater temperatures, produce progeny with an intrinsically reduced metabolic rate. This appears to result in slower maturation and, in the worst cases, the fish may become summer salmon, while less extreme but still adverse conditions may result in progeny that mature a little earlier as spring salmon. More benign environmental conditions may lead to still earlier maturation, resulting in grilse.

Spring salmon, then, are unusual, not least because their maturation compels them to migrate home and stop feeding for up to a full year before they spawn. In energy terms, the higher condition factor of spring salmon allows them to do this. Other factors such as river length and river access may also be critical in determining fitness or reproductive ability.

The most critical factor in the production of springers therefore appears to be stock origin and past enviro-genetic interactions.

Genetics and temperatures

Although genetic variation is generally assumed to be neutral, there is evidence to suggest that natural selection can occur in freshwater salmon populations, revealed in genetic variation at the ME-2 locus (*Verspoor and Jordan, 1989*). Examination of ME-2 genotype frequency distributions in Atlantic salmon from 95 river systems in North America and Europe revealed a correlation with latitude on both sides of the Atlantic and a high correlation with freshwater summer temperatures (ibid).

The enzyme encoded by the ME-2 functions metabolically to assist conversion of substances which are important to the generation of energy. It has been suggested that these enzymes have a prominent role to play in metabolism (*Skorkowski, 1988*). Differences in the timing of maturity may reflect kinetic differences in the ME-2 allozyme.

Investigations into the adaptive significance of ME-2 variation in the Delphi system have revealed significant differences between grilse and MSW salmon (*Anon, 1994a*).

Two possible explanations for this have been put forward. First, that there is only one breeding population and that fish with the potential to become spring salmon diverge at sea from the grilse component. On return to spawn, the two groups, though significantly different in terms of ME-2 following selective survival pressures in the marine, interbreed and the original ME-2 frequency is re-established.

The second possibility is that there are two or more breeding populations, each with its own distinct ME-2 profile and one with a greater potential to produce grilse. ME-2 analysis of juveniles sampled from Doolough's main spawning tributary in 1991 supports the suggestion of two different breeding stocks. The ME-2 profiles of some juvenile samples were almost identical to those of MSW salmon returning two years later (*Anon, 1994 a*).

Evidence for the first hypothesis comes from Iceland, where it has been found that climatic changes in the marine environment may be responsible for long term changes in the sea age composition of salmon stocks (*Gudjonsson et al, 1995*)

At Delphi the three stocks released performed very differently in relation to MSW salmon production, despite being reared and released in similar conditions. Since all three stocks appeared in the high seas fisheries, they might be presumed to have experienced broadly the same marine conditions. This would therefore lend weight to the second hypothesis - that it is the freshwater rather than the marine environment which results in variations in MSW salmon production between populations.

Other studies support the suggestion that the sea age of salmon is determined in freshwater (*Chadwick et al, 1987*). Elsewhere it has been suggested that age and size at maturity are influenced strongly by environmental factors and that growth rates in freshwater, and thus smolt age, depends inter alia on the productive capacity of the river and its temperature regime (*Thorpe & Mitchell, 1981*).

A study of freshwater temperatures at Delphi, Burrishoole and Corrib did reveal significant differences between the locations from April to September, with the Delphi temperatures being consistently the lowest **(Fig. 9).**

Production of higher numbers of spring salmon at Delphi than in the other systems may therefore revolve around the lower temperature regime experienced at the individual or stock level. The slow rate of growth experienced in nursery tributaries or within micro-habitats of a system, where fitness is assured by adoption of slower growth rates to match poorer conditions, may be hereditable.

Through the greater egg size of the Delphi MSW salmon, leading to larger alevins, the progeny may be conferred with a greater fitness advantage than those from grilse ova, leading ultimately to an increased ability to survive the poorest environmental conditions - at the expense of delayed maturation.

Exploitation rates

Even though the Delphi programme has greatly increased rod catches, only a very small proportion of survivors to the Irish coast managed to regain the river. Any enhancement programme in Ireland must contend with the extensive drift net fishery and, in some locations such as Delphi, with an estuarine net fishery. Smaller grilse and early-running MSW salmon may avoid heavy drift net exploitation but are vulnerable to extended estuarine netting, which may be rejuvenated by an enhancement programme.

Exploitation rates will depend on the size and therefore the sex of the fish. The high exploitation by drift nets of the 1992 Corrib-egg group can be explained by the sex ratio. All grilse from this group taken in the river were male. It has previously been found that males of all ages in the Shannon and Corrib stocks were larger at maturity than females (*Went, 1940 and 1943*). Based on rod catches, these Corrib-egg grilse were indeed comparatively large and may therefore have been subject to heavy exploitation by drift nets. It is not clear, however, what happened to all the females, few of which appear to have survived at sea.

Financial and other impacts

The (unexpected) boosting of spring runs of salmon at Delphi, albeit to a modest extent, has added significant commercial value through extending and improving the viable angling season. While anglers' expectations from spring salmon fishing by fly are lower than for grilse, they must believe they have a reasonable catch prospect, something that the Delphi programme has enhanced.

(The extent to which these early runs of MSW salmon have also benefitted from the removal of high seas nets by the North Atlantic Salmon Fund is a matter for speculation, but a significant impact is suspected on 1994 and 1995 rod catches at Delphi).

The desired boost to summer angling prospects has not, however, materialised beyond mid-July. The hitherto highly sought-after sea trout angling month of August remains relatively moribund at Delphi. June and early July, in contrast, are now highly sought-after months due to the enhanced runs of grilse, most notably deriving from the Burrishoole groups.

With Scottish fishery values frequently exceeding £6,000 per average salmon caught, a sustained increase of 100 salmon a year could be worth over £600,000 in capital terms. In that context, Delphi's capital expenditure of £75,000 on the hatchery and annual costs of £40,000 could perhaps be justified. Irish fishery values, however, are generally much lower (and less objectively calculated) than those of Scotland and it is therefore more difficult to justify the Delphi programme in capital value terms alone.

However, the average catch increase deriving from the Delphi hatchery in 1993 to 1995 was 210 salmon per annum and the impact of this on angling and associated accommodation revenue broadly justifies the programme in financial terms.

Conclusion:

Enhancement of spring salmon in Ireland through large scale smolt releases is possible, but not easy. It is also expensive. The main biological barrier to such enhancement is the identification of broodstock which have the necessary genetic ingredients to produce early-running, multi-sea-winter salmon. This in turn means finding a stock with just such a natural proclivity, rather than one which produces late-running MSW salmon.

Having identified a suitable stock, best results are likely to derive from crossing only MSW salmon. This is hindered by the relative rarity of male MSW salmon.

Once smolts from a suitable stock and parentage have been reared and released, they face an arduous sojourn at sea, with a much lower expectation of survival than their grilse counterparts. At best, less than two out of every thousand will make it back to coastal waters.

In Ireland, they then face the offshore drift net fishery, which, though not normally very active in the spring, may change its habits to take advantage of the additional spring salmon runs arising from the curtailment of the Greenland fishery or other enhancement initiatives. Safely past the drift nets, they may in some locations be confronted by an estuarine draft net fishery, legally operating from February on.

These are formidable obstacles.

Fig. 1: Location of fisheries providing smolts for the Delphi programme

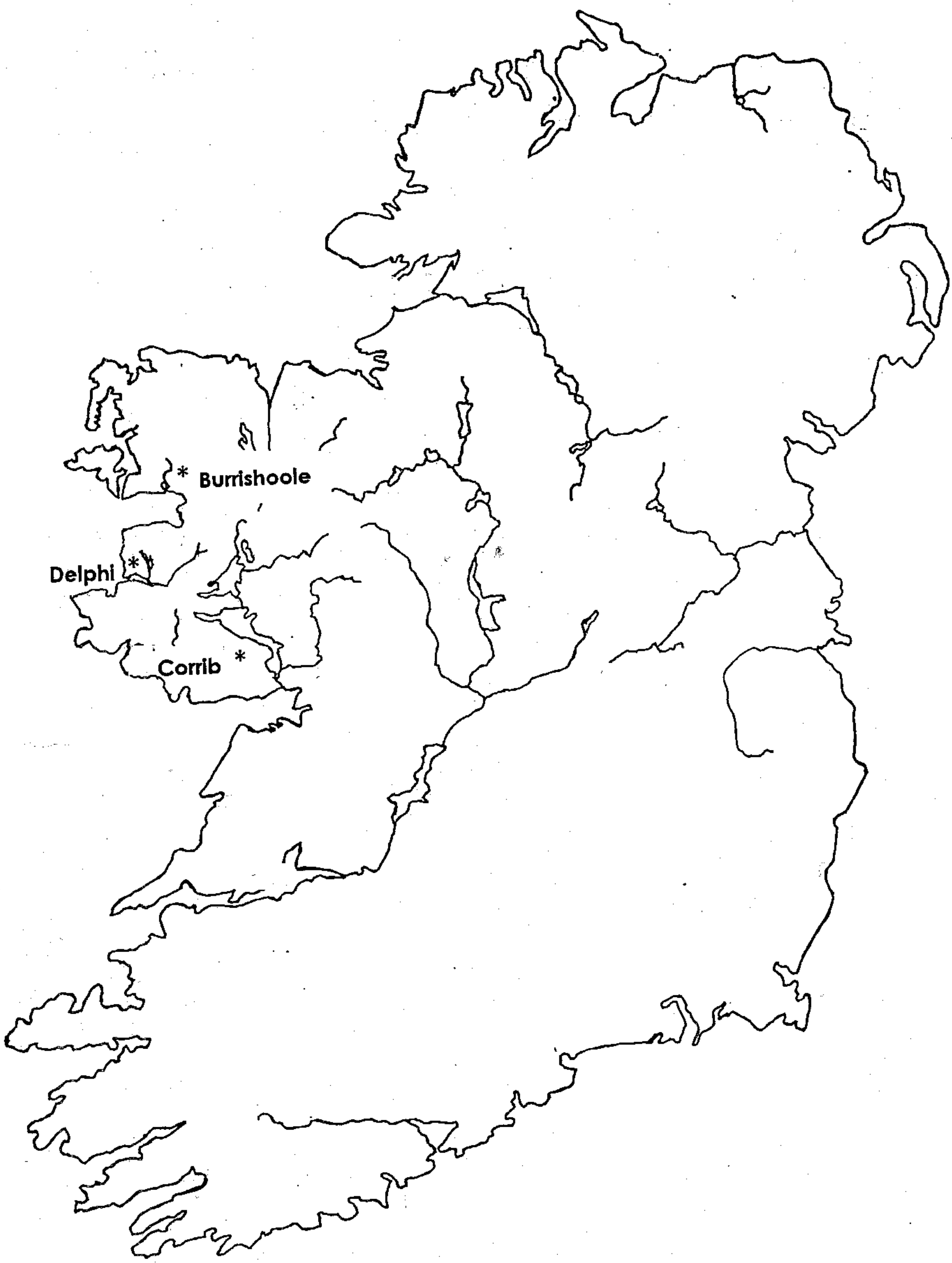


Fig. 2: The Delphi Fishery

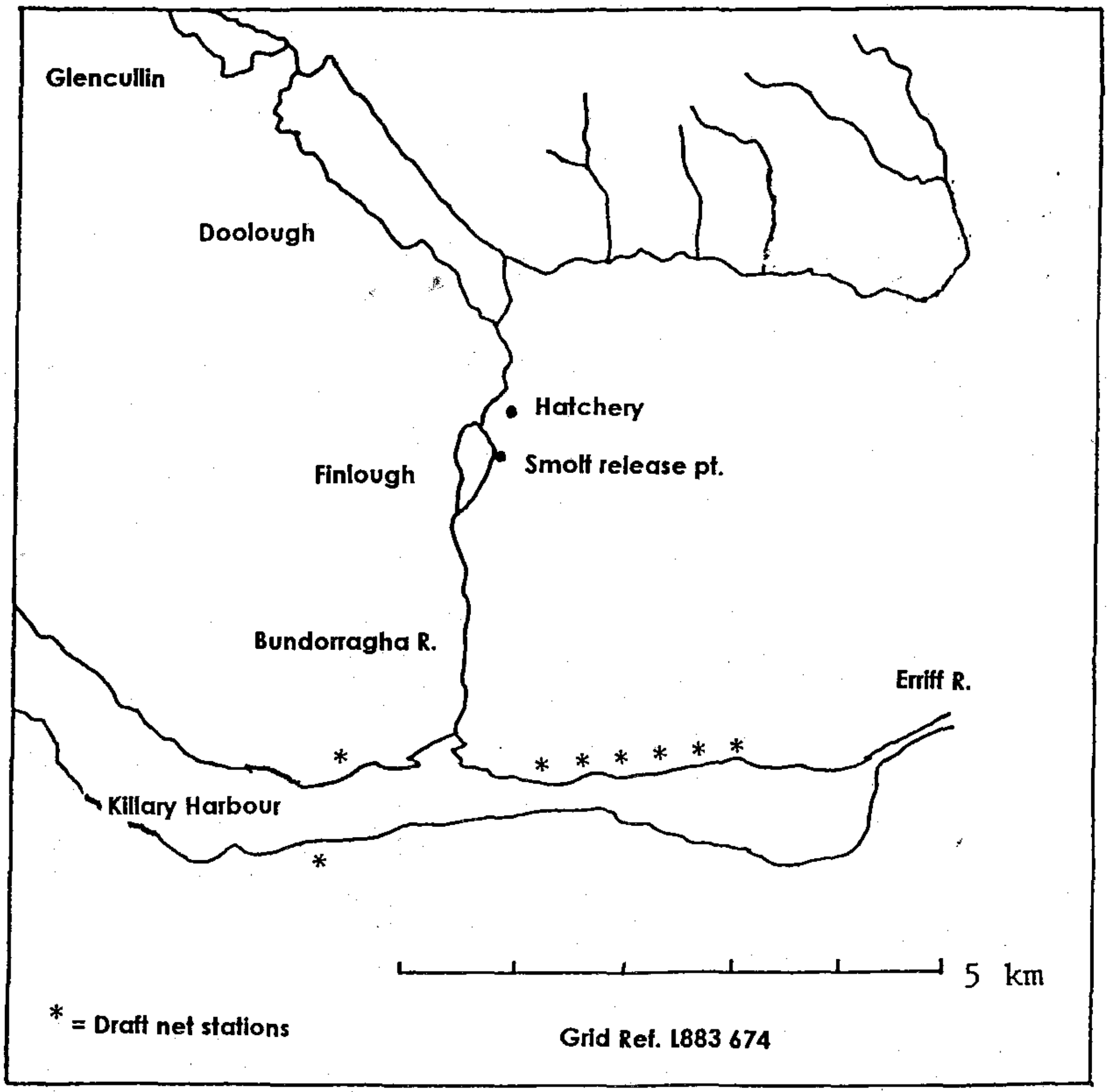


Fig. 3: Delphi sea trout and wild salmon rod catches 1985-95

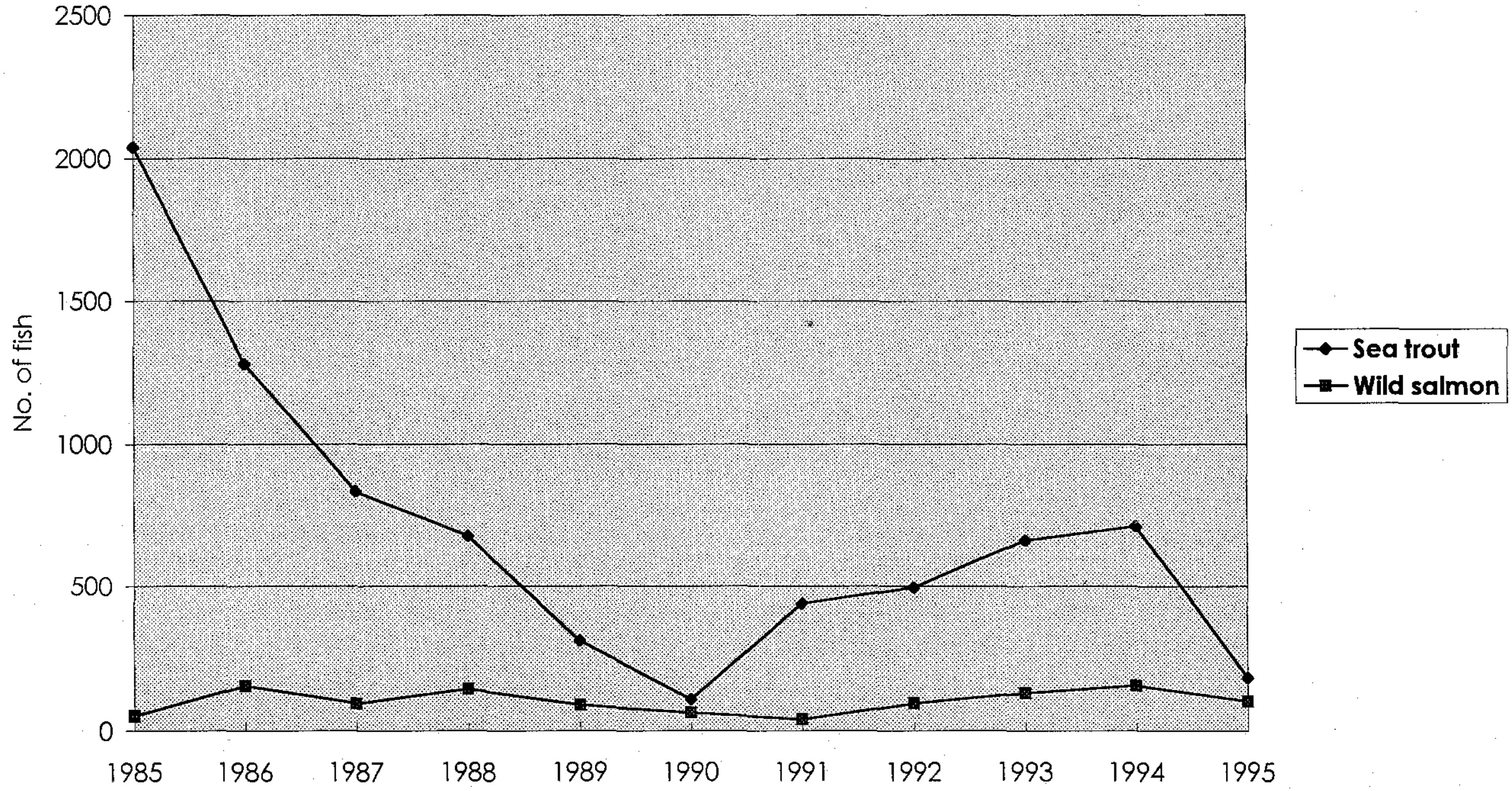
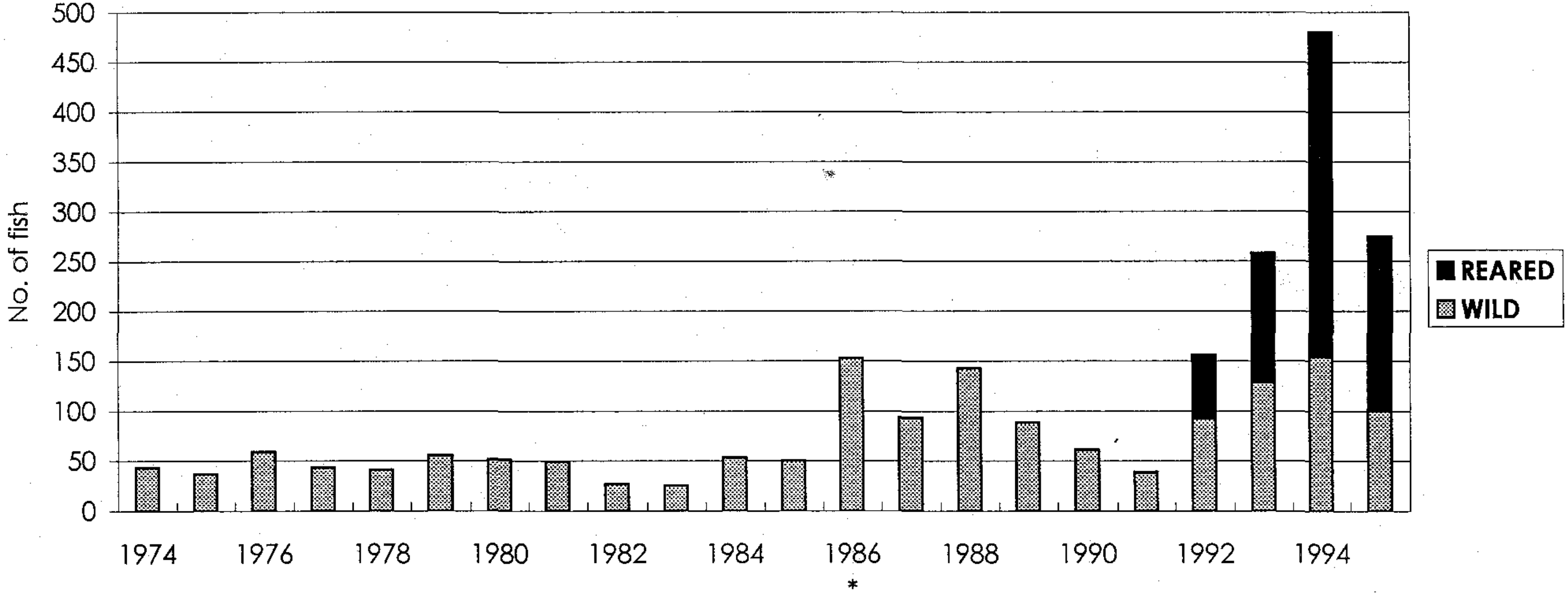


Fig. 4: Delphi wild and reared salmon catches 1974-95



* Change of ownership

Fig. 5: Delphi wild and reared rod catches 1986-95

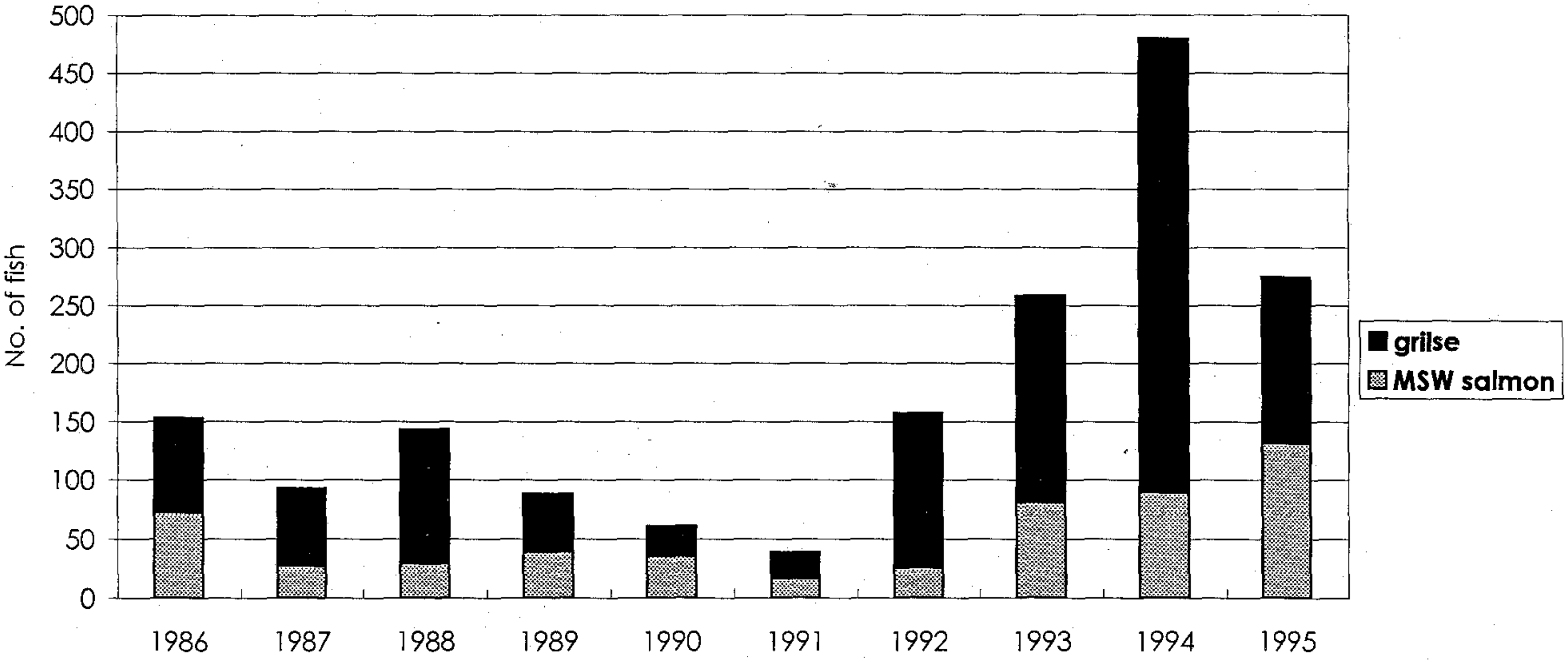


Fig. 6: Capture location of wild and reared salmon caught by Delphi anglers 1992-95

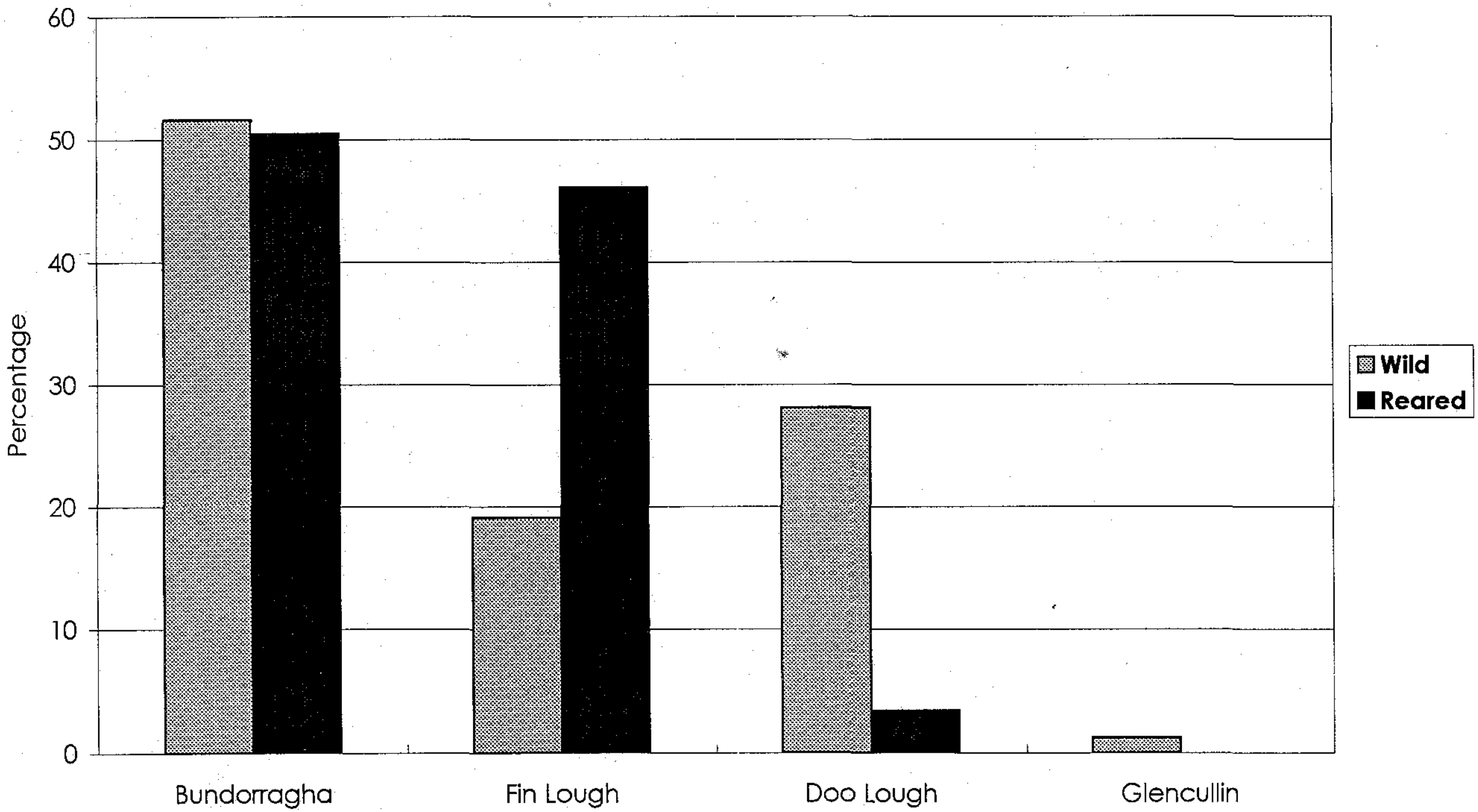
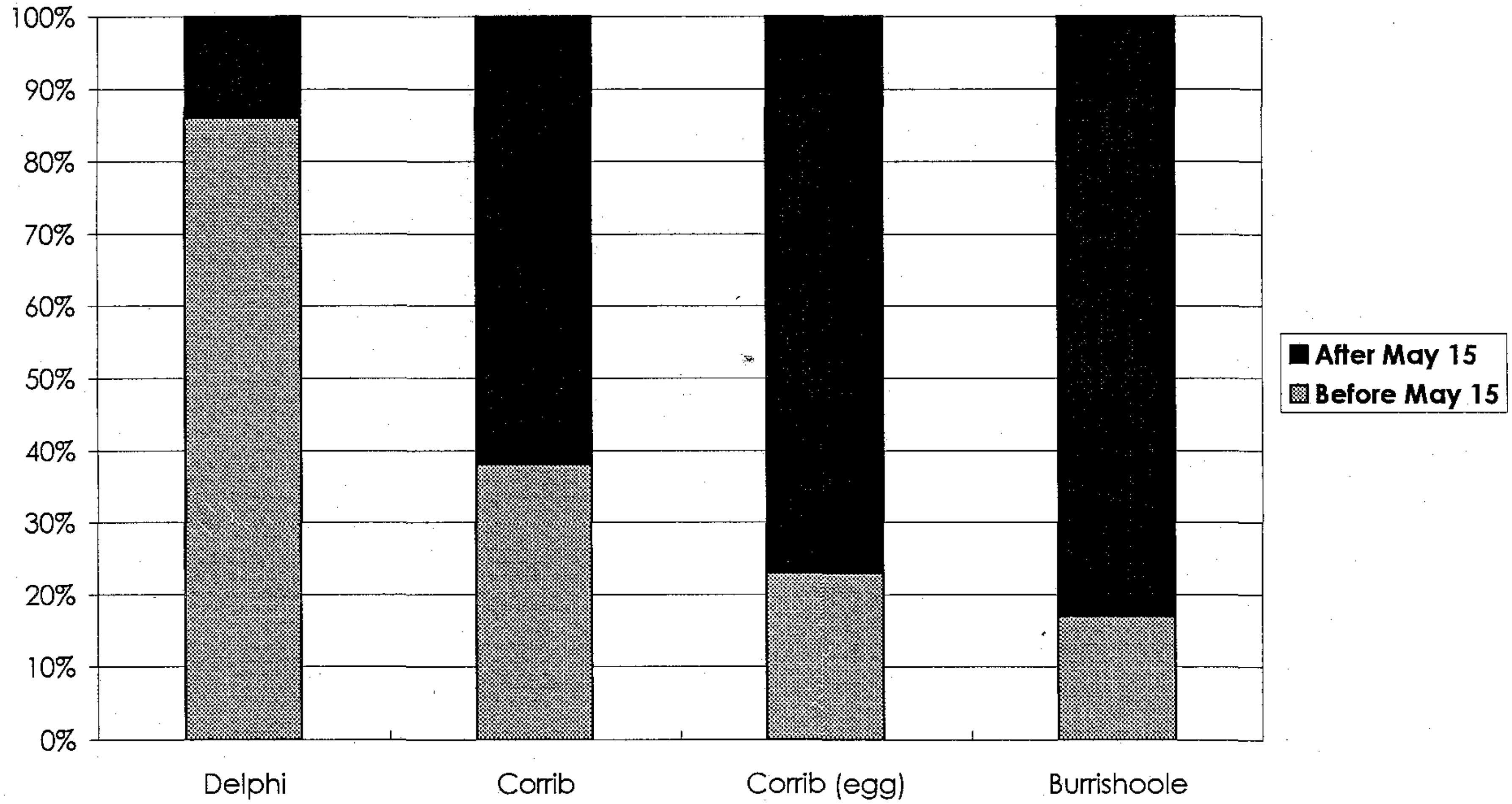
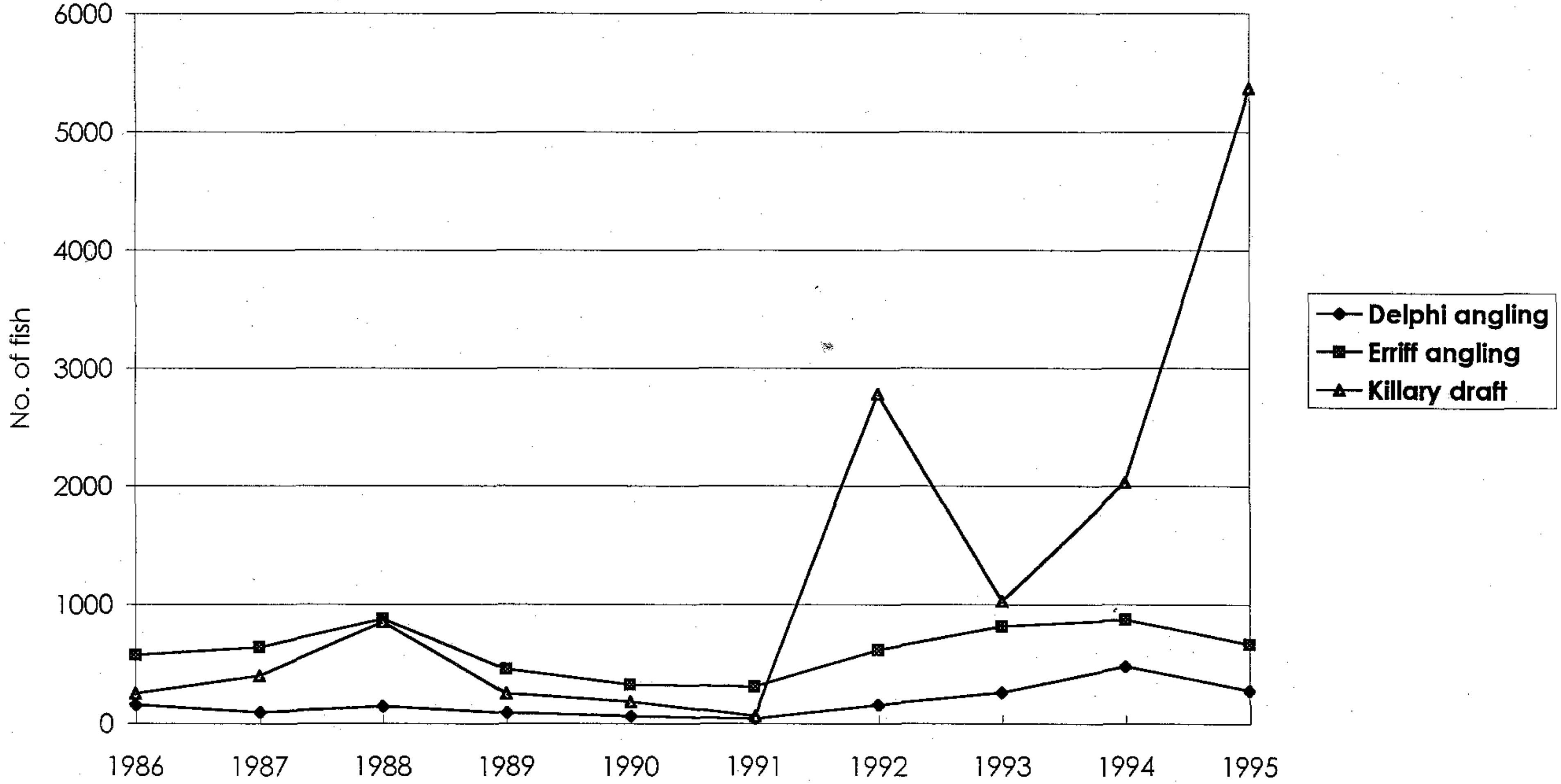


Fig. 7: Percentage of MSW salmon caught* before and after May 15



* catches = drift and draft nets + fresh rod-caught fish, from 1992-95

Fig. 8: Delphi and Erriff* rod catches and Killary draft net* catches 1986-95



* Source: S. Nixon, Western Regional Fisheries Board

Fig. 9: Temperature profiles for hatchery stations 1991

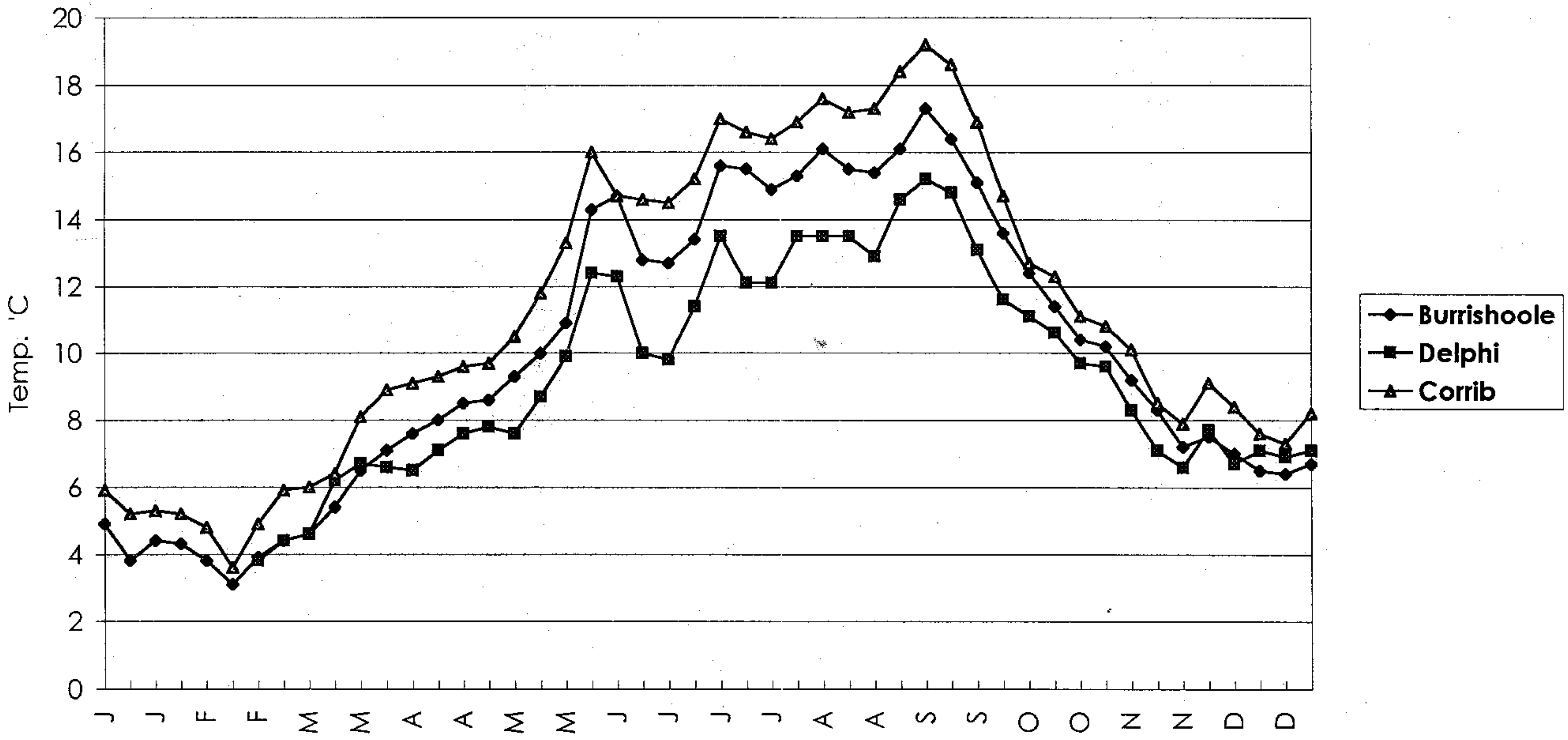


Table 1: Reared stocks released at Delphi 1989 - 1993

Year	Stock	Number
1989	Delphi parr	4,241
1990	Delphi parr	3,242
	Delphi smolts	2,671
1991	Delphi smolts	4,659
	Corrib smolts	10,863
	Burrishoole smolts	9,741
1992	Delphi smolts	8,838
	Corrib smolts	10,844
	Corrib smolts (reared at Delphi)	10,727
	Burrishoole smolts	9,938
1993	Delphi smolts	33,600
	Burrishoole smolts (reared at Delphi)	13,718

Table 2:. Broodstock for reared Delphi groups

Year	No of pairs	MSW * MSW	MSW * Grilse	Grilse * Grilse
1989-90	1		1	
1991	6	4	1	1
1992	11*	-	-	-
1993	19	4	1	14

* Mixed parentage: breakdown unavailable, but predominantly MSW.

Table 3: Delphi rod catches, wild & reared salmon 1986-95

Year	Wild	S	G	Reared	S	G	Total	Smolts* released
1986	153	72	81	0	0	0	153	0
1987	93	27	66	0	0	0	93	0
1988	143	29	114	0	0	0	143	0
1989	88	39	49	0	0	9	88	0
1990	61	35	26	0	0	0	61	2,671
1991	38	16	22	1	0	1	39	25,263
1992	92	20	72	64	4	60	156	40,437
1993	128	45	83	130	36	94	258	47,317
1994	154	54	100	326	35	291	480	50,600 #
1995	100	50	50	174	81	93	274	46,400 #

S = Multi-sea-winter salmon. G = Grilse, # = Not part of study

* Smolt releases in year n contribute to grilse catches in year n+1 and MSW catches in year n+2

Table 4: Survival-to-catch & exploitation rates (per 1,000 smolts)

Rel. date	Stock origin	Survival to catch Tot	S	G	Rod catch S	G	Draft nets S	G	Drift nets S	G	River nets S	G	Strays S	G
10/89	D #	2.1	0.2	1.9	0.0	0.2	0.0	0.0	0.0	1.7	0.2	0.0	0.0	0.0
5/90	D #	3.4	0.9	2.5	0.9	0.0	0.0	0.0	0.0	2.2	0.0	0.3	0.0	0.0
4/90	D	6.4	2.6	3.8	1.5	0.4	0.0	0.0	1.1	3.4	0.0	0.0	0.0	0.0
4/91	D	13.3	6.6	6.7	4.1	0.2	0.0	2.4	0.0	3.9	2.5	0.2	0.0	0.0
4/91	C	79.1	2.0	77.1	0.7	1.5	0.0	30.3	0.0	41.5	1.3	2.9	0.0	0.9
4/91	B	140.3	2.5	137.8	0.9	3.8	0.4	47.3	0.3	77.4	0.9	4.0	0.0	5.3
4/92	D	27.4	6.6	20.8	2.7	1.5	2.0	3.4	0.3	10.4	1.6	5.5	0.0	0.0
4/92	C	37.2	2.5	34.7	0.1	0.5	0.6	5.2	0.6	22.4	1.2	6.6	0.0	0.0
4/92	CE	19.9	3.6	16.3	0.4	0.3	1.4	1.9	1.0	12.5	0.6	1.6	0.2	0.0
4/92	B	96.7	1.7	95.0	0.3	7.1	0.4	9.0	0.6	61.7	0.4	16.7	0.0	0.5
4/93	D	74.8	8.4	66.4	2.3	3.4	3.4	6.9	1.1	49.7	1.5	6.4	0.1	0.0
4/93	BE	147.4	1.9	145.5	0.3	12.4	0.6	22.7	0.9	83.9	0.1	24.7	0.0	1.8

D = Delphi, C = Corrib, B = Burrishoole, E = Eggs reared at Delphi

S = Multi-sea-winter salmon, G= Grilse, # = Parr (all other releases were smolts)

NB. The figures for draft and drift net catches incorporate raising factors (see "Methods")

Table 5: Home water survival, river survival (both per 1,000 smolts) & net exploitation (as % of home water survival) of reared fish

Group	Grilse					MSW Salmon				
	HWS	RS	Tot. nets	Drift nets	Draft nets	HWS	RS	Tot. nets	Drift nets	Draft nets
1990 D	6.0	2.6	56.0	56.0	0.0	7.1	6.0	15.8	15.8	0.0
1991 D	7.5	1.5	80.0	51.4	28.6	16.3	16.3	0.0	0.0	0.0
1991 C	82.6	10.7	87.0	50.3	36.7	2.9	2.9	0.0	0.0	0.0
1991 B	154.8	30.6	80.2	49.8	30.4	4.3	3.7	14.3	4.8	9.5
1992 D	23.6	9.8	58.3	44.0	14.3	13.2	10.8	17.9	2.6	15.3
1992 C	44.8	17.2	61.7	50.2	11.5	2.6	1.3	50.0	25.0	25.0
1992 CE	16.6	2.1	87.0	75.8	11.2	4.5	2.1	54.2	23.0	31.2
1992 B	119.3	48.1	59.7	52.1	7.6	2.2	1.2	45.4	27.3	18.2
1993 D	78.8	22.7	71.1	62.6	8.5	13.6	9.4	30.8	5.9	24.9
1993 BE	191.6	84.7	55.8	44.4	11.8	2.6	1.5	44.4	22.2	22.2

D= Delphi, C = Corrib, B = Burrishoole, E = Eggs reared at Delphi

Table 6: Tag recoveries 1989-95

Rel. date	Stock origin	Number released	Tags recovered			Rod catch		Draft nets		Drift nets		High seas		River nets		Strays	
			Total	S	G	S	G	S	G	S	G	Gr	Fa	S	G	S	G
10/89	D #	4,241	6	1	5	0	1	0	0	0	4	0	0	1	0	0	0
5/90	D #	3,242	7	3	4	3	0	0	0	0	3	0	0	0	1	0	0
4/90	D	2,671	11	5	6	4	1	0	0	1	5	0	0	0	0	0	0
4/91	D	4,659	44	32	12	19	1	0	2	0	8	1	0	12	1	0	0
4/91	C	10,863	318	22	296	8	16	0	66	0	180	0	0	14	32	0	2
4/91	B	9,741	485	24	461	9	37	2	92	1	282	2	1	9	39	0	11
4/92	D	8,838	162	45	117	24	13	5	15	1	40	-	0	14	49	0	0
4/92	C	10,844	227	19	208	1	6	2	28	3	100	-	2	13	72	0	0
4/92	CE	10,727	113	20	93	5	3	4	10	4	63	-	0	6	17	1	0
4/92	B	9,938	532	10	522*	3	71	1	45	2	237	-	0	4	167	0	1
4/93	D	33,600	1,166	156	1,010	78	114	15	61	12	622	-	0	50	212	1	1
4/93	BE	13,718	1,032	11	1,021	4	170	1	84	4	423	-	0	2	339	0	5

D = Delphi, C = Corrib smolts, B = Burrishoole smolts, E = Eggs reared at Delphi
S = Multi-sea-winter salmon, G = Grilse (one-sea-winter salmon), Gr = Greenland, Fa = Faroes
* = Includes one tag recovery from Scotland, # = Parr (all other releases were smolts)

Table 7: Grilse sizes - drift nets v. rod/draft nets

Group	Drift				Rod/draft			
	n	cm	n	kg	n	cm	n	kg
1990 D	3	64.7	3	3.20	-	-	-	-
1991 D	5	63.4	5	2.82	2	61.7	3	2.17
1991 C	103	63.1	100	2.88	80	60.1	80	2.26
1991 B	145	60.7	142	2.61	124	58.0	124	2.06
1992 D	25	62.0	24	2.90	28	60.2	28	2.38
1992 C	61	62.5	62	2.90	33	61.4	33	2.56
1992 CE	45	62.4	43	2.86	13	65.4	13	3.20
1992 B	138	60.5	136	2.60	115	60.0	115	2.35
1993 D	292	60.9	335	2.66	172	55.9	172	1.85
1993 BE	174	58.2	213	2.35	252	54.5	252	1.76

Table 8: Detailed comparison of sizes of 1993 smolt batches with returning adults

Batch & no.	Smolt		Grilse				MSW Salmon			
	cm	g	n	cm	n	kg	n	cm	n	kg
1993 D										
10,562	14.3	32.9	219	58.5	173	2.29	42	74.8	28	4.08
10,374	14.3	33.3	226	58.9	163	2.33	38	74.0	21	4.01
10,605	15.0	38.4	182	60.5	142	2.56	34	74.9	18	4.16
2,059	15.7	44.0	30	61.7	30	2.74	10	75.1	9	4.55
1993 B										
3,473	13.9	29.2	189	55.8	119	1.96				
10,245	14.6	36.3	541	56.5	342	2.05	4	71.5	2	3.30

Table 9: Sizes of all reared smolts and recovered adults

Stock	Smolt		Grilse				Salmon			
	cm	g	n	cm	n	kg	n	cm	n	kg
90D	14.2	33.1	3	64.7	3	3.23	3	75.7	3	4.53
91D	14.4	34.0	9	63.6	9	2.62	29	77.2	17	4.38
91C	16.0	43.0	217	62.0	184	2.61	22	76.9	8	4.68
91B	16.1	46.8	310	59.2	277	2.34	20	74.4	10	4.54
92D	15.3	42.3	116	61.1	53	2.61	42	77.2	30	4.59
92C	16.6	52.9	207	61.8	96	2.75	16	78.7	4	5.13
92CE	14.7	38.4	91	63.2	58	2.95	15	74.3	11	4.28
92B	15.2	41.0	517	60.3	251	2.44	8	75.5	4	4.78
93D	14.6	35.4	657	59.3	508	2.40	124	74.6	75	4.14
93BE	14.4	34.6	729	56.3	461	2.03	5	70.8	3	3.34

Table 10: Sex ratios for adult salmon sampled 1991-95

Group	Grilse			MSW Salmon		
	M	F	M%	M	F	M%
1990 D	2	2	50%	na	na	na
1991 D	2	2	50%	9	21*	30%
1991 C	63	49	56%	4	17	19%
1991 B	82	77	52%	2	16	11%
1992 D	56	20	74%	12	31	28%
1992 C	84	21	80%	3	12	20%
1992 CE	29	0	100%	1	15	6%
1992 B	131	138	49%	1	7	12%
1993 D	297	88	77%	22	122	15%
1993 B	304	283	52%	0	6	0%

na = not available
* = includes two 3-sea-winter fish

NB. Samples taken from rod catches, draft net catches and in-system netting.

Table 11: Ratio of MSW salmon to grilse, wild & reared, caught on rod 1985-93 (Delphi only)

Smolt cohort	Wild G	Wild S	MSW %	Reared G	Reared S	MSW %
1985	81	27	25%			
1986	66	29	30%			
1987	114	39	25%			
1988	49	35	42%			
1989	26	16	38%			
1990	22	20	48%	1	4	80%
1991	72	45	38%	1	19	95%
1992	83	54	39%	13	24	65%
1993	100	50	33%	114	78	41%

G = Grilse, S = Multi-sea-winter salmon (MSW)

Table 12: Size of rod-caught reared Delphi fish* v. wild fish

Year	Grilse n	Grilse cm	Grilse n	Grilse kg	2-sea-winter n	2-sea-winter cm	2-sea-winter n	2-sea-winter kg	3-sea-winter n	3-sea-winter cm	3-sea-winter n	3-sea-winter kg
1990												
Reared	0	0	0	0	4	73.7	4	4.26				
Wild	19	57.9	22	1.95	17	72.8	20	4.09				
1991												
Reared	0	0	1	1.70	17	75.9	17	4.38	2	86.7	2	6.40
Wild	65	56.0	72	1.74	41	71.6	45	3.87				
1992												
Reared	13	58.5	13	2.04	24	76.2	24	4.50				
Wild	79	58.0	83	2.06	51	73.8	54	3.86				
1993												
Reared	113	55.4	114	1.77	76	73.9	76	4.15				
Wild	92	55.5	100	1.83	46	73.2	50	4.07				

* = Delphi groups only i.e. Burrishoole/Corrib groups excluded

Table 13: Delphi Fishing & Accommodation Income 1985-94

	Fishing IR£	Accommodation IR£	Fishermen as % of guests
1985	5,500	Nil*	-
1986	13,755	Nil*	-
1987	25,671	Nil*	-
1988	26,515	20,751	93%
1989	23,379	56,517	88%
1990	13,475	71,395	53%
1991	8,218	100,676	28%
1992	12,145	100,090	31%
1993	19,891	135,250	50%
1994	29,065	180,246 #	57%

* = Lodge derelect until July 1988
# = Lodge capacity expanded by 60% in May 1994

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