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The Commercial Fishery for Barramundi (*Lates calcarifer*) in Western Australia

BY

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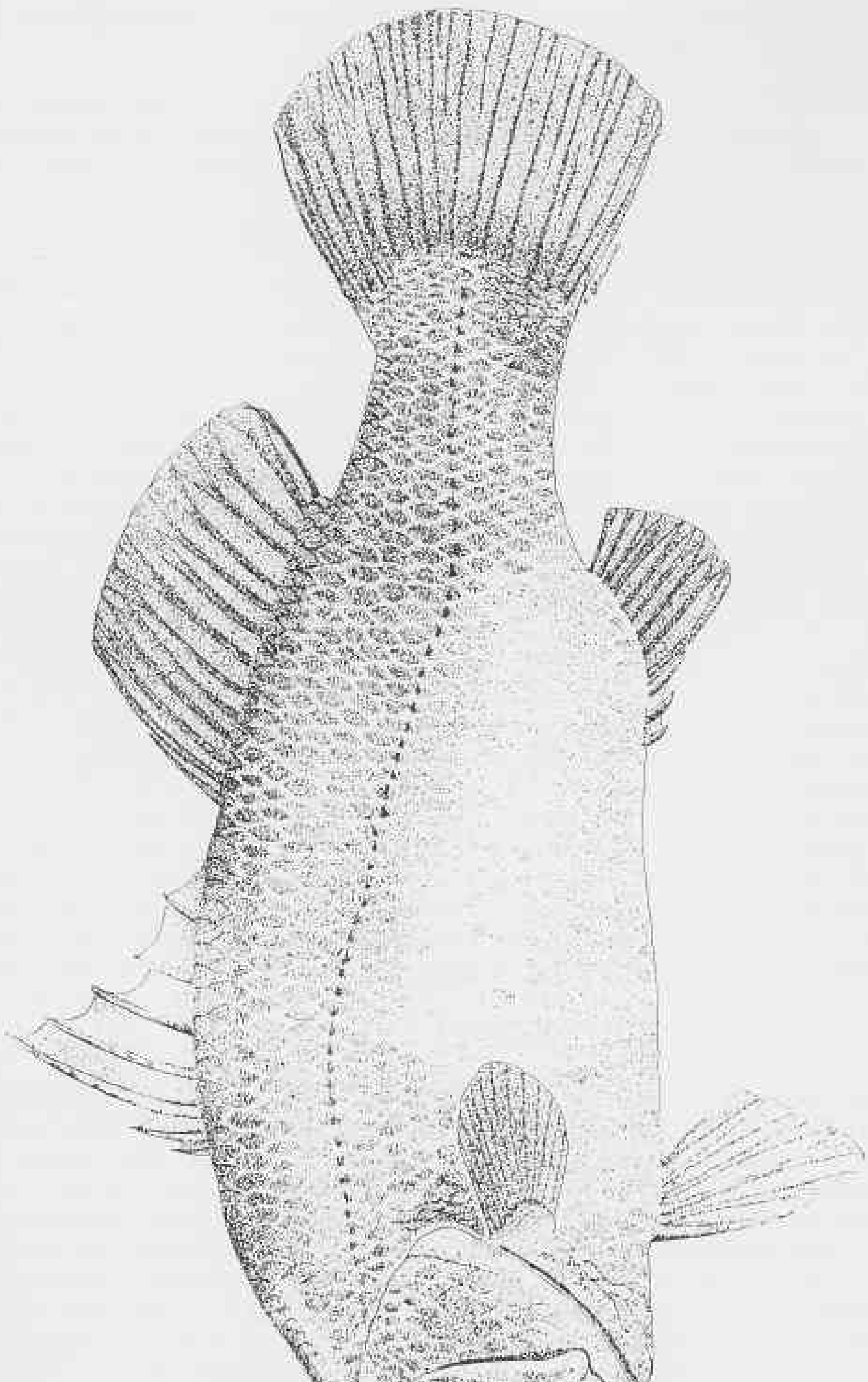

BARRAMUNDI *Lates calcarifer*

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THE COMMERCIAL FISHERY FOR BARRAMUNDI (*Lates calcarifer*) IN WESTERN AUSTRALIA

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ABSTRACT

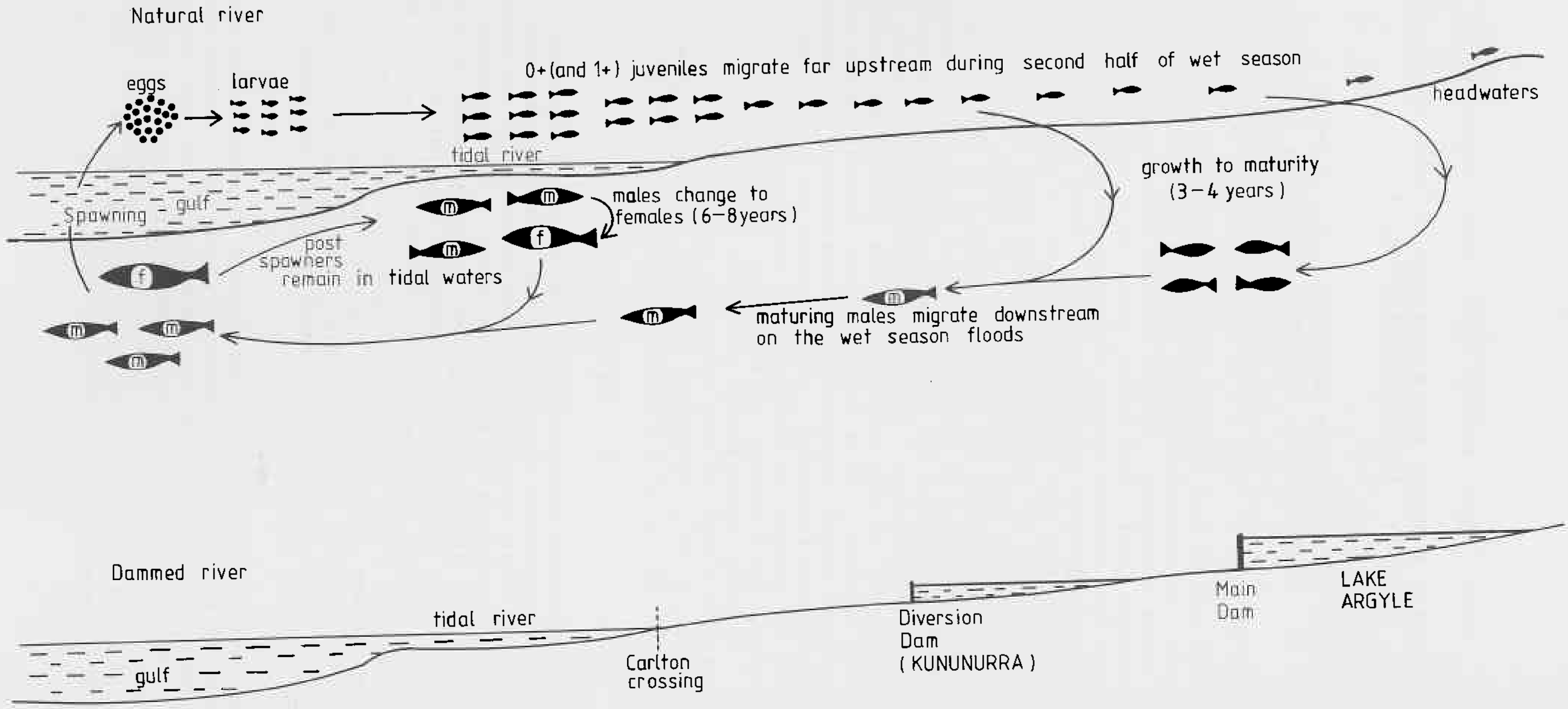
Commercial catch and effort data from the Western Australian fishery for barramundi, Lates calcarifer, over eight years to 1982-83 were analysed. Major stocks and areas of this fishery are Cambridge Gulf (Ord River, port of Wyndham), Kimberley coast, King Sound and Broome coast (Fitzroy River, ports of Derby and Broome), and Pilbara coast (ports of Port Hedland, Roebourne and Onslow) where the Ashburton River is the southern limit to the distribution of barramundi on the west coast. As elsewhere, barramundi stocks are associated with river systems. The low annual catch of about 30 tonnes appears to be due to the limitation placed on abundance by the extent and types of rivers in W.A. Annual fishing effort by land-based operators is limited by flooding during the wet season. So most of the annual catch is taken towards the end of the wet and in the following months of the winter dry season. As a consequence, between year variation in the annual catch appears to be influenced by annual variations in rainfall and flooding. An increase in the annual catch to more than 60 tonnes in 1982-83 was due to an increased catch in Cambridge Gulf where, at Wyndham, rainfall was lower than normal. Fishing operations are also heavily influenced by the extreme tidal range of the north-west which prevents heavier exploitation from port-based vessels, fishing of mud flats, and consistent fishing of isolated rivers on the Kimberley coast.

I INTRODUCTION

Barramundi (*Lates calcarifer*) is a tropical and sub-tropical Indo-Pacific species ranging across northern Australia, down the east and west coasts. The barramundi has an unusual and complex life cycle (reviewed by Morrissy 1983). Only juveniles are found in freshwater and at the approach of maturity they migrate to coastal waters to spawn during the wet season (catadromy). Adult fish remain in coastal waters and the tidal reaches of rivers. Most of the adult stock are male fish; the few larger and older female fish result from a change in sex later in life (sex inversion, protandry). The commercial fishery is restricted to coastal and tidal waters of rivers and juvenile stocks inland can only be legally exploited by amateur (sport) fishing.

The barramundi is renowned throughout Australia as gourmet restaurant fare and as the north's premier-and virtually only worthwhile freshwater - sporting fish for residents and the burgeoning tourist trade. However, the resultant increasing demand for barramundi, the reduction in the extent of accessible habitat in freshwater for juvenile stocks as a consequence of damming of rivers, and increasing conflict between the interests of professional and sport fishermen,

Barramundi Life Cycle
(*Lates calcarifer*)



Taken from: Morrissy,N.M. 1983, Potential Fisheries Capability of the Ord in the Short, Medium and Long Terms. *Fish. Rept. West. Aust.* 59, 1-24.

including tourist bodies, indicate the desirability for assessment and closer management of stocks. This report examines catch and effort statistics for the commercial fishery in Western Australia. Data provided by The Australian Bureau of Statistics (ABS), from a monthly log sheet returned by each professional fisherman as a condition of a boat licence, are currently available on computer file from the start of the 1975-76 year.

II THE ANNUAL CATCH FROM THE FISHERY

The total annual catch, by all fishing methods in all areas along the north-west coast, had increased by 1982/83 to more than 60 tonnes from a previous level of about 30 tonnes (Table 1).

Therefore, it is of timely interest to examine the data in more detail in an attempt to provide answers to the following questions necessary for future management of the fishery: Was the increased catch in 1982/83, and previous year to year variations, a direct reflection of changes in fishing effort and, more specifically, a large increase in effort in 1982/83? Or were these changes, in a highly variable monsoonal climate, a reflection of good and poor seasons either so far as barramundi stocks or fishing conditions were concerned?

Perspective is also required on the magnitude of barramundi stocks in W.A. with the knowledge that the W.A. catch of 30 or 60 tonnes is very low compared to that of the Northern Territory (range, 1972-80, 382-1054 tonnes), Queensland ($\sim$ 1 000 t, Gulf of Carpentaria and East Coast), and Papua New Guinea (220-400 t). Whether the W.A. annual catch to date represents a major degree of under exploitation, or fishing from small stocks limited by the extent of favourable habitat, should be borne in mind.

Factors controlling the monthly fishing effort for barramundi also require detailed analysis, i.e. whether market demand, experience of likely fishing success (availability of fish), or seasonal conditions - such as flooding influencing access to fishing grounds, produce a seasonal fishing pattern.

III CATCHES BY VARIOUS FISHING METHODS

Most (93-96%) of the total annual commercial catch was taken by setting mesh nets specifically for barramundi in the tidal reaches of rivers and in coastal tidal creeks (Table 1). Other methods, excepting perhaps hand lining, caught barramundi incidentally; e.g., while trolling for mackeral offshore. Apart from netting, hand lining was the only (other) method showing a trend in annual catch and monthly returns, indicating a specific increase in fishing for barramundi. Incidental trapping of barramundi and other fish adjacent to Broome for local consumption declined over the years. The number of monthly returns each year for set-netting appeared to be directly related to the magnitude of the annual catch.

Barramundi are not the only species of economic value caught by coastal set netting. Other species included on the monthly returns were salmon catfish (several species) and sharks. Salmon catfish have been implicated in barramundi substitution in the N.T. It is not known by how much the W.A. barramundi catch is inflated by this practice, which has occurred in the N.T. when fish are marketed by the fishermen as fillets.

Monthly returns record the weights landed of whole fish, headed and gutted fish, gutted and gilled fish, or fillets. These weights have been converted to whole fish weights in the ABS system by the following approximations which, unfortunately, to date have not been determined specifically for barramundi in W.A.. Headed and gutted weight was coded as equivalent to gutted and gilled weight which was multiplied by 1.25 to give whole fish weight. Fillet weight was multiplied by 2.37.

In the author's experience, prior to 1975 professional fishermen on the Fitzroy River supplied barramundi to meet the demands of local supply (hotels, hospitals) in Broome and Derby. These fishermen had no refrigeration or chilling facilities at the fishing camp sites. Netted fish were often tethered alive as dead fish deteriorate very rapidly in this hot region without refrigeration or chilling in ice boxes. Barramundi taken to the towns were seen hanging gutted and gilled, but not headed, in large cold rooms in the towns' stores. Subsequent to 1975 there has been an increased demand, and higher prices, from capital city markets for barramundi. This has seen a change to recording of catches as fillets and headed and gutted weights in monthly returns which, no doubt, represents a change in processing encouraged by the greater efficiency of refrigeration and lower transport costs in these forms.

IV COASTAL DISTRIBUTION OF THE ANNUAL CATCH

The locations of catches in monthly returns are recorded by fishermen from a system of 'blocks' numbered from degrees of latitude and longitude (Fig. 1). The rivers and localities (towns) associated with these blocks are shown in Table 2. Blocks tabled are those recorded in returns against coded species 552, barramundi. In some localities several adjacent blocks have been grouped for analysis, e.g., Broome coast. Very small catches were occasionally recorded from offshore blocks (not overlapping the coastline), probably incidental to trolling or trawling for other target species.

Occasional returns for the Carnarvon (Gascoyne River) and Dirk Hartog Island blocks recorded less than 10 kg of fish per month and were undoubtedly due to misidentification of the sand-bass, *Psammoperca waigiensis*, also often called reef barramundi. No *Lates calcarifer* have been observed by fisheries research staff over many years of extensive trawling and other fishing operations in the Shark Bay area. From the present data and taxonomic collections of the W.A. Museum (R.J. McKay, pers. comm.), the southern limit to the distribution of barramundi on the west coast of Australia is the Ashburton River near Onslow.

The distribution of annual catches taken by netting in coastal blocks shows that the main and most consistent fishing areas have been the Ord and other smaller rivers flowing into Cambridge Gulf near Wyndham, the Fitzroy River flowing into King Sound near Derby and the coastal tidal creeks near Broome (Table 3). Sporadic fishing and generally low catches have been recorded in Kimberley rivers between the Fitzroy and Ord Rivers. In latter years consistent fishing has occurred farther south particularly in the Port Hedland - De Grey River area (Pilbara coast).

Most of the increased total annual catch in 1982/83 was due to a large increase in catch in the Wyndham area.

Ashburton River - near Onslow. Southern limit to the distribution of barramundi on the west coast of Australia. *above and below*.

Also shown in Table 3 are values for catch per unit of fishing effort (c.p.u.e.). C.p.u.e., has been calculated as catch (kg) per day per 100 m of net, the method employed for calculating catch rate in the Northern Territory fishery. Catch rates for W.A., may be underestimated on this basis since one 'day' of fishing as recorded actually involves only about 10 hours of net setting time (see below).

C.p.u.e., values for the N.T. fishery declined steeply from the range 20.5 - 28.8 in the early seventies to 7.4 - 8.6 in the late seventies due to a large increase in fishing effort (Rohan *et al* 1981). In Papua New Guinea, the catch rate was in the ranges 20-43 in 1965 and 15-20 by 1979 with nets permanently set along the coast; freezer boats recorded catch rates up to 100 using mono-filament net and the fishery in 1979 was regarded as being under-utilized (Hill and Grey 1979).

In the Cambridge Gulf, the larger catch in 1982/83 was associated with a very high catch rate of 46.1 using the N.T. values for comparison or by reference to early years of lower total catches in W.A.

Between King Sound and Cambridge Gulf (inaccessible readily by land), catch rates and sporadic fishing appear to indicate low stocks, associated with limited favourable habitat (short, steep rivers rising on the Mitchell Plateau), unable to sustain continual fishing (see Discussion, (iii)).

The fishing grounds associated with the Fitzroy, Robinson and the smaller May-Meeda Rivers flowing into King Sound showed high and sustained catch rates with continuing fishing over the period but no increased total catch in 1982/83. On the other hand the Broome fishery with low, but not declining, catch rates showed a marked increase in total catch in 1981/82 and 1982/83 from previous very low levels.

Farther south, with the advent of consistent fishing in the Port Hedland - De Grey River area, the catch increased to the level of the Fitzroy and King Sound areas but present catch rates here and further south may be more an initial reflection of increased fishing efficiency rather than the level of, or changes in, stocks.

V ANNUAL CATCH AND EFFORT STATISTICS FOR MAJOR STOCKS

As shown in Table 3, complete series of annual data from 1975/76 were available for (i) Broome coast, (ii) Fitzroy River (Derby), (iii) Outer King Sound (Derby) and (iv) Cambridge Gulf (Wyndham).

Monthly fishing effort components recorded on returns were; average length of net (m) used during a month, average number of days fished per month, average number of hours fished per day, and average number of shots per day.

Average length of net showed appreciable variations between years but no tendency for increase, over the years. For Broome coast, the overall mean was 182 m (range between years, 72-251); Fitzroy River, 99 (74-147); King Sound 121, (50-205); and Cambridge Gulf, 169 (103-346). (It must be assumed that the monthly return showed the average of the total length of all the nets used on each trip during a month, if a number of nets were employed, and not the average individual length of a number of nets). These short net lengths are consistent with the use of one, or more, 50 to 100 m (~ yards) nets to "block off" small tidal creeks or channels on the fall of a tide. In the N.T., net lengths can approach 1 000 m (with a limit of 1 500 m). There, as well as net fishing in rivers and tidal creeks, very long nets are set on open mud flats, a method that it is said is not possible to employ in the north west (see Discussion).

In section IV, annual catch rate (c.p.u.e.) was based upon an annual fishing effort, e, which was calculated by summing the monthly values for the mean number of 100 m net lengths used per day multiplied by the number of days fishing per month. A more appropriate unit of monthly fishing effort, and denominator for c.p.u.e., can be calculated as either e' = (e x mean number of shots per day) or as e" = (e x mean hours of fishing per shot x shots per day). With an average monthly value of one shot per day e' = e. Since each shot is based upon a tidal cycle influencing the movement of barramundi (see Discussion IV), the important additional daily variable is shots per day and not hours of fishing per day which is mostly determined by shots per day.

(i) Broome Coast

The annual catch for Broome coast oscillated about one tonne until the 1981/82 season when it increased to 4 tonnes and then to nearly 8 tonnes in the 1982/83 season. These catch values were closely paralleled by changes in total fishing effort as e', i.e., number of 100 m net lengths x shots (Fig. 2). (Effort calculated as e" gave a similar graphic pattern of association, but as e a much poorer one). This increase in effort was due to an increase both in the number of boats operating in the area, and in the mean number of shots per day from a level of 1.0-1.3 up to the 1981/82 season, to 1.8 in 1981/82 and 3.0 in 1982/83.

Catch rate, as c.p.u.e'., although low relative to the other areas of the fishery, showed no tendancy to decline with increased effort. However, the years 1976/77 and 1977/78 were highly anomalous.

(ii) Fitzroy River (Derby)

Annual catches, fishing effort, and c.p.u.e'. were stable over the period, taking into account the low catch and effort in 1975-76 (with only one boat providing returns) and changes in the number of boats (Fig. 3.).

There was some suggestion of an association between lower catch rates and higher annual rainfalls at Derby, i.e., flooding, but no significant statistical correlation was present. (P = 0.12). However, catch rate as c.p.u.e'., showed the usual negative relationship with fishing effort (e), (P = 0.047), when variation in annual rainfall was included in regression analysis. The highest catch, and c.p.u.e'., was recorded in 1978/79, a year of low rainfall, the lowest over the period: Otherwise catch was closely linearly related to effort.

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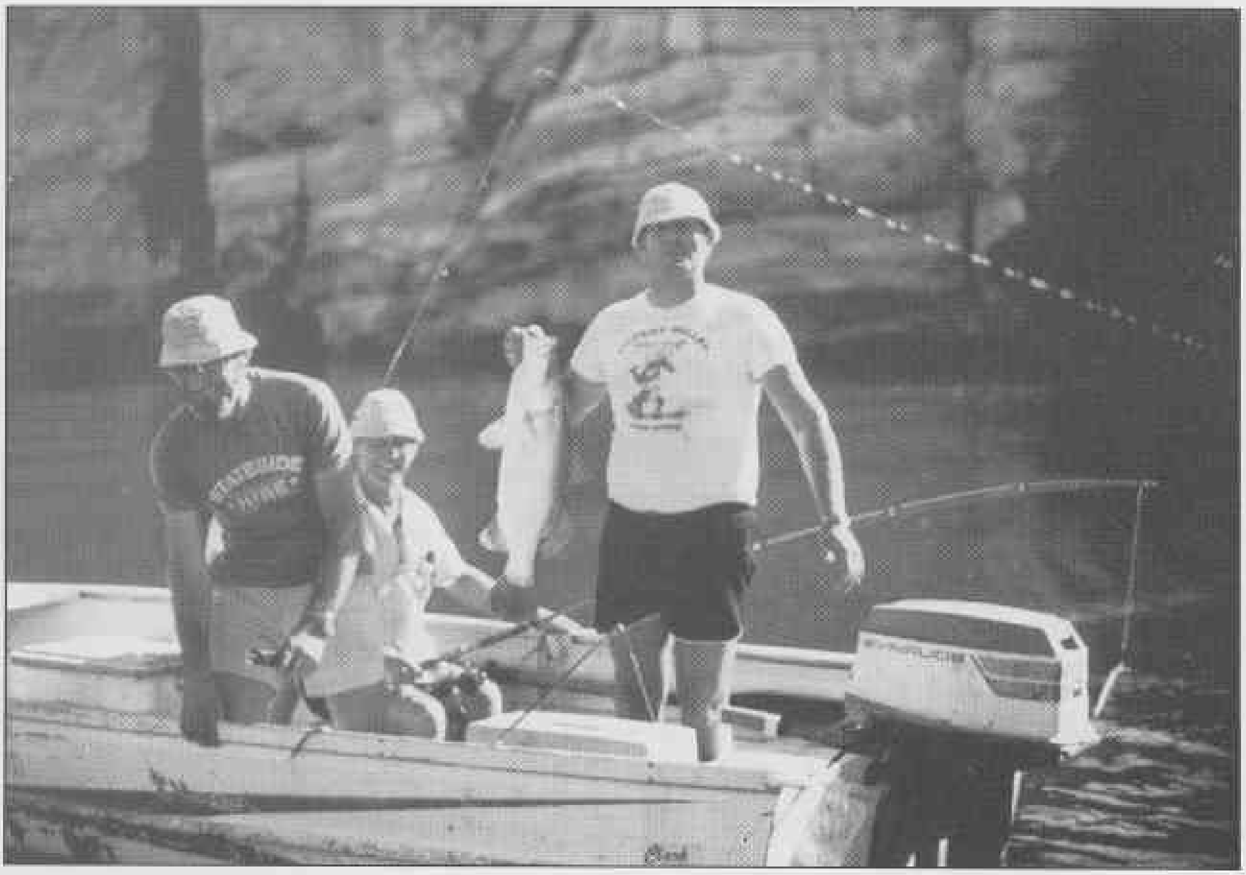


Geikie Gorge - amateur fishing trip.

Fitzroy River - late March,in flood. Willare Bridge in background.

(iii) Outer King Sound

Catch again was closely related to effort (e'), with one to three boats catching about 2 tonnes per year (Figure 4). Five boats fished in the high rainfall year of 1977/78 yielding a catch of over 7 tonnes; this catch was not repeated in the next year of similarly very high rainfall, 1981/82. In the dry year, 1978/79, catch rate (c.p.u.e'.) was unusually high for an annual catch of about two tonnes. This feature was not shown in the previous dry year, 1976/77.

The adjacent block, Fitzroy River, also showed a high catch in the dry year, 1978/79, and a higher catch but an average fishing effort level in that year.

In contrast to other areas, shots per day for this more remote block (from a coastal town, i.e., Derby) varied from 1.8 to 3.4 after 1975/76.

(iv) Cambridge Gulf (Wyndham)

The annual catch from this area varied around 11 tonnes until the 1982/83 season when it increased to 27.7 tonnes with 5 boats, the number operating since 79/80 (Fig. 5). Catches, did not reflect the high fishing effort, e', in 1978/79 or 1981/82, the only two years of very high rainfall over the period. Consequently catch rate, as c.p.u.e'., was lower than usual in these two years. Catch rate was highest in 1976/77, the driest season over the period, and fishing effort was lowest in that year.

The near equivalence of fishing effort in the high rainfall year 1978/79 (e' = 920, 100 m net lengths x shots) and in the lower rainfall year 1982/83 (e' = 888) resulted in catches of 10.9 tonnes and 27.7 tonnes respectively. In 1978/79 3 boats fished on average net length of 346 m for 266 days (10.3 hours/day, 1.0 shots/day) while in 1982/83, 5 boats fished an average net length of 113 m for 531 days (13.6 hours/day, 1.5 shots/day).

The evident relationship between annual values for catch rate, as c.p.u.e'., total fishing effort, e', and Wyndham annual rainfall, R mm, (Fig. 6) were described statistically by a multiple regression equation as follows:

$$c.p.u.e'. = 101 - 0.0331\ e' - 0.0685\ R\ mm$$

This relationship was significant at $P < 0.01$, $F\ (2,5) = 13.6$, with E' at $P = 0.024$ and R mm at $P = 0.027$, describing 91.9% of the variability in c.p.u.e'. (adjusted R square = 78.3%).

The expected relationships from this equation for c.p.u.e'. and total fishing effort, e', or rainfall, R mm, for different levels of rainfall and effort, respectively, are shown in Fig. 6.

The corresponding relationship between total annual catch and total annual fishing effort, as e', are shown in Figure 7 for different levels of rainfall, noting that the mean and median annual rainfalls for Wyndham are 775 and 821 mm, respectively, based upon the long term record of calendar years.

VI MONTHLY DISTRIBUTION OF THE ANNUAL CATCH

The total monthly catch for the whole fishery by gill-netting in coastal blocks showed considerable variation within years and between years for particular months (Table 5). Catch, mean catch per boat, and the number of returns per month tended to be lowest during the expected height of the wet season, i.e., January and February. Fishermen relate that fishing operations are limited, or prevented, physically by flooding during the wet season and may be reduced during the coldest months of the dry season because of inactivity of the fish at lower water temperatures (A. Wann, Derby, pers. comm.). Widespread heavy rainfalls occur intermittently during the wet season and variably between years, with the passage of cyclones; rivers rise, and flooding abates, rapidly. Considerable variability in monthly and annual catches can be expected from this influence on total monthly fishing effort and also on catch rate. This aspect will be examined more closely for the Wyndham area in the next section.

However, it is worthy of note here that the N.T. fishery is similar in this regard with the lowest monthly catches having been recorded during the height of the wet season (January and February) in years prior to the introduction of the present closed season (October - January) there (Grey and Griffin 1979). By contrast, monthly catches on the east coast of Queensland are positively correlated with river flow, i.e., the highest monthly catches occur during the wet season (Dunstan 1959). Dunstan (1959) considered that movement of barramundi increased their likelihood of capture in traps and set nets and was promoted by flooding; the latter does not appear to present a major obstacle to fishing activity in Queensland as it does in the N.T., and W.A.

The total fishery has seen a consistent increase in the number of boats since 1980/81. However, the number of months fished per boat each year based on monthly returns supplied by each boat remained relatively constant at 4.2 annually over the years. Table 5 shows that not all the boats fished every month and, as shown later for the Cambridge Gulf area too, it is unusual for all the boats to be fishing in any one month of the year. The only 'economic unit' possible in this fishery is considered to be one which fishes 'whenever fish are available', necessitating additional means of livelihood at other times. (Note: professional fishermen are required to spend 51% of a year fishing as a condition of licensing). In this regard a monthly catch of 200 kg per boat has been indicated by fishermen as a minimum level of return and Table 5 shows that catches often fall below this level in January and February. So the likelihood of exceeding the minimum economic catch for barramundi may be an important incentive for fishing in particular months.

In considering any proposal for a closed season over the fishery, to complement those in the N.T., (October - January) and Queensland (November - January), the mean proportion of the total annual catch taken from October to January, inclusive, was 24.8% (33% expected) with a range of 17.0 to 36.0 over the years (Table 5). From November to January, the mean proportion was 17.3%, with a range of 11.7 to 23.9.

For the N.T., Grey and Griffin (1979) gave the January and February catches as 2.5% of the annual catch; the corresponding values for W.A., are 3.4 and 3.3%, respectively, for the period 1975-1983.

VII MONTHLY CATCH AND EFFORT IN THE CAMBRIDGE GULF FISHERY

The highest mean monthly catch over the 8 years in the Cambridge Gulf area occurred for April when the wet season rainfall abruptly tapers off (Fig. 8). The catch remained high through May to August and then fell to a low level in October. After rising somewhat in November with the start of higher rainfalls, the catch then fell to low levels through December, January and February but increased in March when rainfall was still high. Total shots per month as a measure of fishing effort, and catch per shot, as a measure of catch rate, showed similar monthly trends to catch, except that the low catch during February was achieved with a high catch rate (Fig. 8).

The mean number of monthly returns per boat (for all boats that fished at some time during a year) also showed similar trends to catch values (Fig. 8). The maximum proportion of boats fishing in a month was 63%, in May, and the minimum was 24%, in December and January. Since the mean number of boats over 8 years was about 5, these proportions correspond to 3 and 1 boats, respectively. However, for boats, or the boat, fishing in a month, the mean number of shots per return, varied little, from 11.5 to 15 except for lower values in December and, particularly, February (Fig. 8).

VIII DISCUSSION

(i) Distribution and abundance of stocks

Stocks of barramundi in the North of W.A., continue through from the N.T., and range down the west coast where the limit of their southern distribution is the Ashburton River (22°S) near North-West Cape.

On the bases of consistency of fishing over the present period of analysis of the fishery and the slopes of the catch/effort relationships in different areas, Cambridge Gulf (2 blocks) supports the highest abundance of fish, followed by the Fitzroy River - Inner King Sound (1 block) and the Outer King Sound (1 block). Combining the two King Sound blocks to give a comparison on an area basis with Cambridge Gulf, the total catch in King Sound approached that of the Gulf in most years but with a higher expenditure of fishing effort. Lastly, in terms of areas consistently fished, the Broome Coast (4 coastal and 1 offshore blocks) yielded catches at the lowest level of catch per unit of fishing effort. On the Kimberley coast between Cambridge Gulf and King Sound, the inconsistent fishing and low catches may partly indicate the difficulties of fishing there, in terms of tidal ranges (see

(iv) below) and lack of ports and land access, but also the extent of favourable habitat for stocks (see (iii)). In the southern part of the fishery, Pilbara coast, lack of consistent fishing until recently would indicate low stocks; the high catch rates, as occasionally on the Kimberley coast, with more consistent fishing recently may be a reflection of fishing on previously unexploited, or intermittently exploited, stocks.

(ii) Stocks

The problem of identifying different, i.e., isolated breeding, stocks, requiring separate monitoring and management, in the coastally extensive W.A. fishery necessitates a subjective approach because of lack of biological and catch information. Although barramundi are a highly mobile, migratory species, the presence of stocks is strongly related to river systems (Dunstan 1959) and genetically isolated stocks are known to occur in Northern Australia (Davis 1984 b).

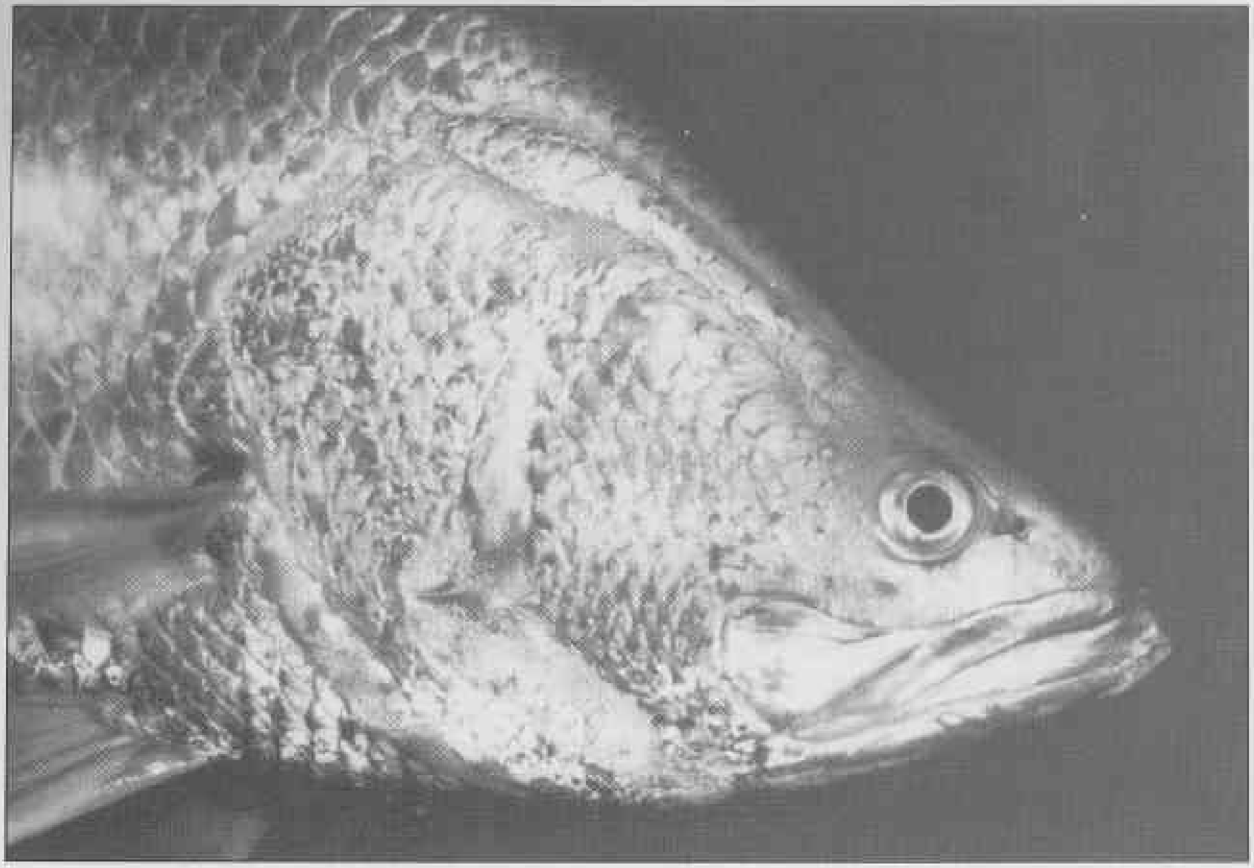
Four major stocks, or areas of stocks, can be defined at the present time. Firstly, the major stock in Cambridge Gulf influenced by the Ord River; secondly, the King Sound-Broome coast stock influenced by the Fitzroy River; thirdly the Kimberley coast; and, fourthly, the Pilbara coast.

Within each of these major stock-areas it is not possible from the present knowledge of the fishery to assess the contributions to the catch of more specific localities or individual rivers. This aspect is of particular importance in the case of the Ord River in Cambridge Gulf where the access to inland waters by juveniles and the annual flow regime has been greatly modified by damming. In 1963 the completion of the Diversion Dam (Lake Kununurra) henceforth prevented farther upstream movement of juveniles but did not significantly alter the annual flow regime. In 1971 the completion of the Main Dam (Lake Argyle) effectively dampened the extremes of wet season flooding of the Ord. More importantly, perhaps, dry season overflow from Lake Argyle has been continuous since damming (except for a brief cessation in 1979) and the lower Ord has had a strong perennial flow.

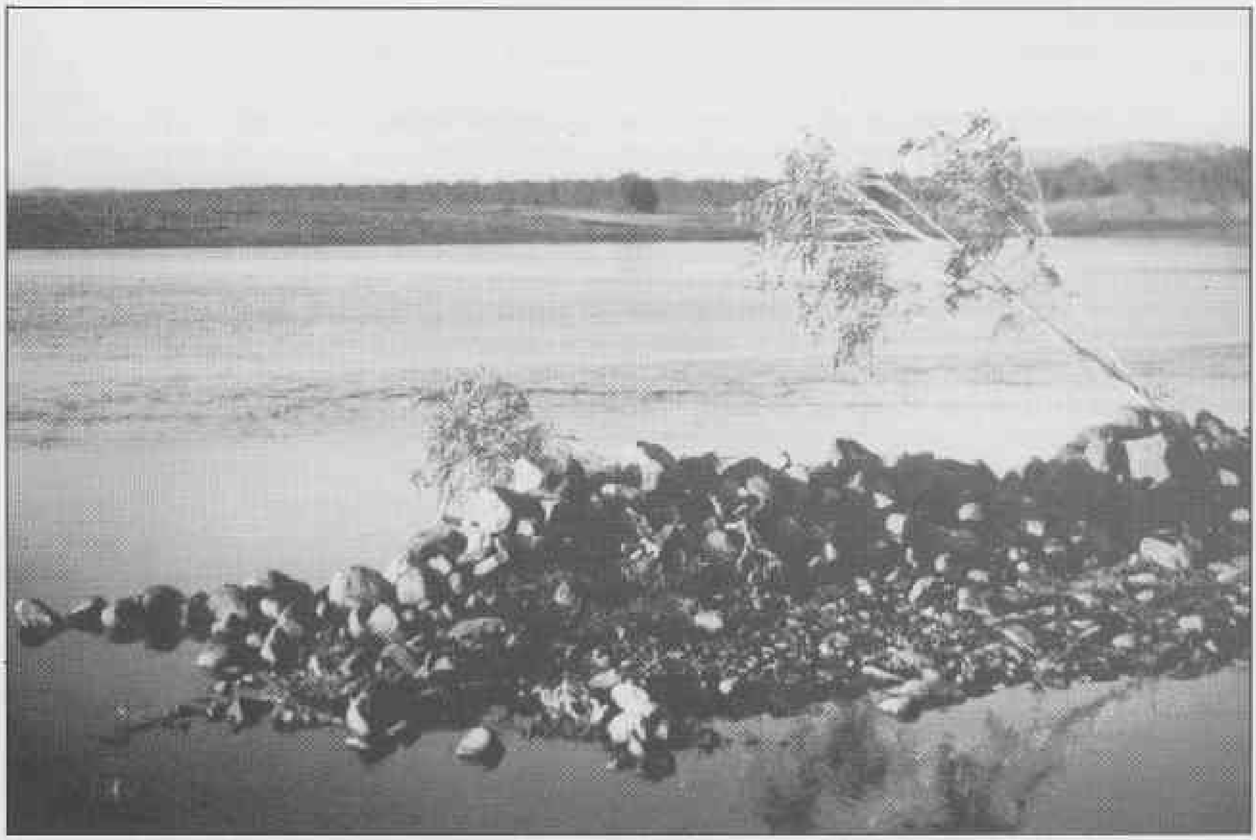
(iii) Habitat association and life history

Until recently Dunstan (1959) provided the only biological information on barramundi in the Australian region. In some respects his pioneering description was incorrect, e.g., for growth rate (Hill and Grey 1979, Reynolds and Moore 1982), incomplete, e.g., on the sex change from male to female (sex-inversion, protandry) (Moore 1979, Davis 1982), and presents only a simple picture of the relationship between the catadromy of the species, its habitat requirements and early life history (Garret 1979, Moore 1982, Moore and Reynolds 1982).

Most of the current difficulty in managing barramundi fisheries lies in establishing the significance of catadromy in their life cycle, i.e., the extent of migration between



Barramundi - sex unknown, not yet mature.



Carlton Crossing - tidal limit of the lower Ord River and the upstream limit for professional fishing.

inland and coastal waters involving juvenile growth in rivers and spawning in the sea. For example, this question concerns the conflicting interests of commercial fishermen in tidal waters, exploiting the breeding stock, and sport fishermen inland, where only juvenile stocks occur (see below), and also the influence of damming of rivers on total juvenile production.

Dunstan (1959) and the more recent research findings in northern Australia and Papua New Guinea, cited above, together with accounts of hatchery work in Thailand, have clearly established that barramundi only ripen in brackish or tidal waters and spawn in coastal waters at salinities approaching that of oceanic seawater. In P.N.G., the spawning ground associated with the Fly River stock is a considerable distance from the river because of the very high freshwater discharge. In Australia spawning does not appear to require lengthy coastal migration and may occur before significant river discharge commences at the start of the wet season.

It is also clear that only juvenile (immature) fish (albeit to 15 kg in weight) are found inland in river pools and associated freshwaters. At the approach of maturity, at 3-4 years of age, these fish migrate to tidal waters to ripen as males and spawn with older, larger females there during the wet season. Once mature, fish remain in tidal waters during the subsequent dry season. Dunstan (1959) found that recently spawned, o+-group, juveniles migrated into freshwater during the wet season and 1 + - group fish already inland moved farther upstream in rivers.

However, this catadromous model of the life history is now known to be too simplistic; in particular the behaviour and distribution of juveniles is more complex and variable with juvenile fish being found in both tidal and freshwaters. Dunstan (1959) himself noted that juvenile production is not wholly dependent on access to freshwater in observing that a greater percentage of immature fish are found in freshwater than in tidal or brackish water.

In P.N.G. residual stocks of both adult and juvenile fish remain in coastal waters but the majority of 1 + and older fish, including adults during the non-spawning season, live in inland waters (Moore and Reynolds 1982). 0 + group fish live in freshwater coastal swamps until these dry up and then in coastal waters until they move into rivers during their second year of life. In northern Australia, newly hatched barramundi larvae are carried, or swim, into shallow nursery areas (coastal river flood plains, mudflats, swamps) on the spring tides and later, as post-larval juveniles, move into other tidal areas or inland (Russell and Garrett 1983). Movement of juveniles to tidal waters during the dry season has been observed in Queensland when inland water temperatures are low.

Dunstan (1959) appeared to suggest that physiological intolerance of higher salinity water, more so in juveniles than adults, was the basis for movement inland and so was the reason for the association between abundance of stocks and river systems. However, there is no evidence that barramundi are not a completely and highly adaptable euryhaline species from an early age (e.g., Moore and Reynolds 1982; rearing tests in seawater at the W.A. Marine Research Laboratories on Fitzroy River fish from 0+ to 6 years of age) i.e. they can live in, and move between, seawater and freshwater.

From an evolutionary viewpoint the catadromy shown by barramundi represents an intermediate stage of adaptation of a primarily marine species for invasion of freshwater. Many other species of Australian percoid fish are products of a similar invasion including those that now breed and live exclusively in freshwater, as do the African species of *Lates* (e.g., Nile perch) and the Murray-Darling percoids, or those that still have some reliance on brackish waters for spawning (e.g., *Percalates* spp on the eastern seaboard).

Thus from this viewpoint, migration of juveniles into freshwater represents extension of the range of the species into an ecosystem where the niche of a large predatory fish is otherwise unoccupied in northern Australia. Barramundi can grow to a size of about 15 kg in inland waters before maturity, e.g., in Geike Gorge on the upper Fitzroy River. The only other major aquatic predator is the freshwater crocodile but these do not prey on large fish (R. Griffin, pers. comm.). Movement into freshwater by juveniles has the selective advantage of separating them from possible predation in coastal waters by the stock of parent barramundi and other species. At least in the Kimberleys, the upstream migration of juvenile barramundi during the latter half of the wet season follows the extensive migration from brackish waters of *Macrobrachium* spp, which are favoured food of barramundi.

This present model implies that production of juvenile barramundi is dependent upon the presence and extent of freshwater systems which seem to be a major factor in determining the abundance of adult stocks, i.e., commercial fisheries. However, it is also apparent that migration to freshwater is not an obligatory part of the life-cycle and that there is some lower baseline contribution to adult stocks from juvenile production in tidal waters, albeit in or close to estuaries.

Dunstan (1959) described five types of barramundi habitat in Queensland, categorized in terms of abundance of juvenile stocks, as follows:

(a) Rivers with a large catchment, muddy or sandy beds, sluggish and meandering (low relief), with a medium to slow, but continuous, flow, i.e., flow during the dry season, but not subject to extreme changes in flow during the wet season. These rivers provide the best riverine habitat for juveniles.

(b) Short, deep, straight fast flowing rivers rising on small catchments in ranges receiving high rainfall. These rivers have physical barriers to upstream movement of fish and support very few juveniles.

(c) Impermanent rivers, with sandy or rocky beds upstream, which reduce to isolated water holes in the dry season. Barramundi are absent upstream and scarce in the lower reaches.

(d) Freshwater streams and swamps, near the coast in high rainfall areas, that are permanent during the dry season and connected to coastal waters during the wet season. Juvenile barramundi are plentiful in this type of habitat.

(e) Small tidal creeks, in mangrove swamps, receiving little freshwater. Barramundi are rare in these creeks.

Applying these descriptions to W.A. rivers, there are no type (a) rivers. The two major rivers, the Ord and Fitzroy, are closer in description to type (c) rivers, although obviously more favourable. For example, extensive permanent pools are frequent in the lower reaches, their gradients are low enough to permit juveniles to move far upstream during the wet season (in the Ord before damming). On the other hand the Pilbara rivers are typical type (c) "desert" rivers. The rivers on the Kimberley coast, arising on the Mitchell Plateau, most closely approach the type (b) river description. There are no extensive permanent coastal freshwater streams and swamps, i.e., type (d) habitats, in W.A., although such swamps and lagoons are a prominent juvenile habitat in the N.T. during the dry season. As juvenile habitat, the Broome coast fits the type (e) description most closely although there is significant runoff in many small creeks, e.g., on Roebuck Plains, during the wet season. However, it is not known to what extent the Broome coast fishery is dependent upon recruitment from the Fitzroy River.

The extent of tidal creeks in coastal mangrove swamps may be of greater significance in W.A. than described by Dunstan (1959) for Queensland. This type of habitat fringes most of Cambridge Gulf and, to a lesser extent, is predominant in King Sound. But it is sparse on the largely, rocky, steep Kimberley coast and on the barren, desert Pilbara coast (Map - "The coastal environment of Western Australia". Coastal Management Co-ordinating Committee, Perth, 1984).

The extent of shallow coastal mudflat, flood plain, saltpan and swamp habitat for larval and post-larval barramundi during the wet season requires appraisal in W.A. in terms of permanence with the large tidal range. There are extensive areas of mudflats in Cambridge Gulf and King Sound.

Although a perspective on the W.A. fishery can only be discussed at this very superficial level at present, the above comparison does provide an explanation for the low W.A. catch relative those of the N.T., and Queensland.

(iv) Fishing methods and variability between years and seasons in fishing effort

It is clear from the present statistics that fishing effort is markedly reduced during the wet season, which produces the reverse of the seasonal catch pattern obtained on the east coast of Queensland where the monthly catch is a maximum at the height of the wet season and is low during the dry season. At least in the Cambridge Gulf area of the fishery, rainfall also partly influences variation in the annual catch between years, with a lower annual catch rate in years of above average rainfall.

It is not clear from the present statistics whether, or not, high freshwater discharge of rivers and run off from the land reduces the availability of barramundi, i.e., catchability, by affecting their pattern of behaviour and distribution. However, it is known from fishermen that, because fishing operations are land-based, access overland to fishing areas is curtailed, or prevented, during times of extensive flooding of low-lying coastal areas during the wet season.

This feature of the present fishery indicates a likely increase in exploitation of barramundi stocks if wet season access to fishing grounds were to be improved if development of the northwest should provide all weather tracks (which is very unlikely), or if port-based mother-craft were to be employed. In fact, the latter alternative as a means of increasing fishing effort, has been attempted, e.g., from Derby along the Kimberley coast, but has been largely unsuccessful because of the other inhibiting factor peculiar to the Kimberleys, the extreme tidal range. Use of runabouts from the mother-craft to fish the tidal estuaries and creeks is extremely dangerous and costly in terms of fuel because of the speed of tidal currents, and logistically difficult because of the necessity to set and retrieve nets at certain times during the tidal cycle. Use of larger port-based craft to set very long nets on tidal mud-flats, as in the N.T., is also not practiced in W.A., because of tidal currents and range.

The common land-based method of net-setting in tidal creeks for barramundi is to set towards the high tide when fish have entered the creeks. (It is a common experience to hear the surface 'slap' of barramundi feeding on mullet and other small fish following the tidal wave in estuaries). The head ropes of set nets are run around the base of a mangrove tree on either bank at the opening of a tidal creek. The ends of the head ropes are then brought back to the centre of the net and tied so that the net can be retrieved on the fall of the tide. Usually the net is anchored further to maintain a vertical barrier as fish move out of the creek on the fall of the tide. Very large barramundi are held against the net by the tidal current rather than gilled. Obviously the difficulties of maintaining nets in these circumstances limits the length of each net, and hence size of creek opening, that can be fished. And the critical timings of net setting and retrieval on the tidal cycle, limit the number of nets that can be fished.

IX CONCLUSIONS

(i) The annual catch from the W.A. barramundi fishery has been small relative to those of the N.T. and Queensland and appears to be due to the limited extent and quality of juvenile habitat.

(ii) Total annual fishing effort is curtailed by the influence of flooding during the wet season on land access to fishing grounds. Variability between years in this factor has also partly influenced the annual catch at least in the Cambridge Gulf area.

(iii) The approximate doubling of the annual catch in 1982/83 was mainly due to a like increase in the catch in Cambridge Gulf where annual rainfall in that year was below average.

(iv) For the purposes of management, the W.A. fishery may be partitioned into four separate stocks or areas, the Cambridge Gulf stock, the King Sound and Broome coast stock, the Kimberley coast area, and the Pilbara coast area.

(v) Because damming of the Ord River, preventing migration of juveniles upstream of Kununurra, occurred well before 1975, it is not possible to say from the present data what affect damming has had on the abundance of the Cambridge Gulf stock of barramundi. However, on the basis of catch data and annual catch, this stock appears to have been more abundant since 1975 than the stock in King Sound (Fitzroy River) and from the stocks in the other areas of the fishery.

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TABLE 1: ANNUAL CATCH (kg) OF BARRAMUNDI BY FISHING METHOD. NUMBER OF MONTHLY RETURNS FOR EACH BOAT AND BLOCK IN PARENTHESES

FISHING METHOD	1975/76	1976/77	1977/78	1978/79	1979/80	1980/81	1981/82	1982/83
TROLLING (03)				865	451	149	20	101
				(3)	(5)	(4)	(1)	(2)
HAUL NETTING, BEACH SEINING (04)	1053	314	394	275		313	29	100
	(3)	(5)	(1)	(1)		(1)	(2)	(4)
TRAWLING (05)							19	6
							(1)	(1)
TRAPPING (12)	628	1301	1439	284	156	289	44	163
	(11)	(9)	(13)	(11)	(3)	(8)	(7)	(6)
HANDLINING (13)	165	115	118	1199	306	397	1708	2408
	(2)	(2)	(1)	(3)	(4)	(10)	(16)	(25)
MESH SET AND GILL NETTING (15)	15749	22893	35325	32693	24249	30768	26125	61705
	(39)	(70)	(82)	(81)	(76)	(103)	(99)	(147)
TOTAL CATCH BY ALL METHODS	17595	24623	37276	35316	25162	31916	27945	64483

TABLE 2: RIVERS AND LOCALITIES CORRESPONDING TO BLOCK NUMBERS RECORDED ON COMMERCIAL LICENCE RETURNS FOR THE BARRAMUNDI FISHERY. SEE ALSO FIGURE 1.

RIVER AND/OR LOCALITY	COASTAL BLOCK NO.	OFFSHORE BLOCK NO.
Ord, Durack, Chamberlain, King Rs, Cambridge Gulf-Wyndham	1428,1528	
Berkeley R	1427	
Drysdale, King Edward Rs-Kalumburu	1326,1426	
Lawley R	1425	
Prince Regent R 1525		
Aboriginal Reserve	1524	
Isdell, Charnley Rs	1624	
Robinson R, Outer King Sound - Derby	1623	
Fitzroy, May-Meeda Rs Derby	1723	
Broome Coast (tidal mangrove creeks)	1622,1722,1822,1821	1721
Eighty Mile Beach	1921	1819,1820
De Grey R and distributory-Port Hedland	1919,1920,2019,2018	
Harding, Sherlock Rs-Roebourne	2017	1917
Fortescue, Robe R	2016,2115	2015,2014
Ashburton R - Onslow	2114	2113
Gascoyne R - Carnarvon	2413	
Dirk Hartog Island	2512	

TABLE 3: DISTRIBUTION OF THE BARRAMUNDI FISHERY ON THE WESTERN AUSTRALIAN COAST.

[1] Annual catch, kg; [2] catch per day per 100 m of net (c.p.u.e.).
Catch and effort values are for coastal blocks and the main fishing method, mesh set and gill netting (code 15). The block number tabled is the reference block for one or more adjacent blocks, see Table 1.

River/locality/ identifying block	1975/76	1976/77	1977/78	1978/79	1979/80	1980/81	1981/82	1982/83
Cambridge Gulf (1428)	10943[1] 49.3[2]	11286 63.4	15679 29.5	10916 11.9	10998 33.3	11628 35.0	7098 13.6	27704 46.1
Berkeley R (1427)								1781 3.2
Drysdale, King Edward Rs (1326)			1800 7.2	1289 23.9	3220 6.9			2310 4.0
Lawley R (1425)							4319 9.5	2738 15.2
Prince Regent R (1525)			1184 62.3	2564 42.1		1906 6.9		
Aboriginal Reserve (1524)		75 25.0	521 31.0	875 19.4	685 71.4		490 9.8	
Isdell, Charnley Rs (1624)	3132 23.4	2043 53.3	1622 36.1	3884 22.7	756 9.8			74 2.6
Outer King Sound (1623)	59 11.8	1360 19.4	7253 27.3	2288 38.8	926 15.7	3514 26.6	1037 23.0	2447 24.5
Fitzroy R (1723)	1141 21.5	6718 18.3	6414 18.3	9314 30.7	6945 21.7	7213 23.7	5727 21.2	6810 17.2
Broome coast (1622)	406 2.0	1411 8.3	852 13.3	1563 3.9	719 5.4	1327 2.4	3998 7.6	7740 8.0
80 Mile Beach								
De Grey R, Pt. Hedland (1919)						1173 11.5	2224 8.8	6014 15.6
Harding, Sherlock Rs Roebourne (2017)						3654 42.5	1156 12.5	1247 75.1
Fortescue, Robe Rs (2016)	68 11.3					253 1.1		65 6.7
Ashburton R, Onslow (2114)							671 16.2	1737 19.7

TABLE 4: TIDAL RANGES (metres)

	MHW-MLWS[1]	MHWN-MLWN[2]
Darwin	5.5	1.9
Wyndham	6.6	2.9
Port Warrender	6.4	0.8
Derby	9.8	4.3
Broome	8.2	1.8
Port Hedland	5.8	4.4
Onslow	1.8	0.6

[1] Mean high and low water spring tides, resp..

[2] Mean high and low water neap tides, resp..

From: Australian National Tide Tables 1984, Australian Government Printing Service 1983. Table IV. Tidal levels at standard ports Part 2: Predominantly semi-diurnal and mixed tides.

TABLE 5: Monthly total catch kg[1], monthly mean catch per (block -) boat[2], and the number of monthly returns for all boats (by block)[3], for gill netting employed in the barramundi fishery.
The proportion (%) of the annual catch taken in months considered as a future closed season are shown.

YEAR/ MONTH		07	08	09	10	11	12	01	02	03	04	05	06	Annual	No. of boats	Oct-Jan%	Nov-Jan%
	1	1515	937	1050	1054	1013	292	1063	289	2637	2609	2117	1173	15749			
1975/76	2	379	312	525	264	507	146	532	96	527	522	706	293	404	12	21.7	15.0
	3	4	3	2	4	2	2	2	3	5	5	3	4	39			
		1372	2137	1289	1532	2585	1433	1458	1127	2041	1242	2995	3682	22893			
1976/77		343	427	322	383	430	358	208	187	227	207	428	460	327	19	30.6	23.9
		4	5	4	4	6	4	7	6	9	6	7	8	70			
		6169	3995	2936	1849	1805	1091	1246	1025	916	3090	6785	4418	35325			
1977/78		685	400	419	264	361	218	415	342	229	441	617	402	431	17	17.0	11.7
		9	10	7	7	5	5	3	3	4	7	11	11	82			
		4360	4009	2727	5073	2961	1900	1825	778	2237	3359	213	3251	32693			
1978/79		396	501	303	507	423	271	365	156	373	560	213	542	404	17	36.0	20.5
		11	8	9	10	7	7	5	5	6	6	1	6	81			
		1634	2047	3976	1143	1129	1469	1117	1588	2930	1072	3036	3228	24249			
1979/80		272	292	497	191	376	294	186	265	419	214	337	404	319	18	20.0	15.3
		6	7	8	6	3	5	6	6	7	5	9	8	76			
		4452	2580	2447	2312	3181	1898	946	1485	1760	5374	2286	2047	30768			
1980/81		405	235	272	193	353	237	189	297	251	597	286	227	299	23	27.1	19.6
		11	11	9	12	9	8	5	5	7	9	8	9	103			
		2931	2432	941	1228	2009	1213	113	977	2776	3018	4017	4157	26125			
1981/82		326	243	134	136	251	243	113	195	308	335	335	346	264	26	17.5	12.8
		9	10	7	9	8	5	1	5	9	9	12	12	99			
		10922	6610	6650	5599	6735	4328	688	1049	3415	5772	3722	5444	61705			
1982/83		840	413	475	400	561	333	115	131	379	481	338	302	420	35	28.1	19.0
		13	16	14	14	12	13	6	8	9	12	11	18	147			

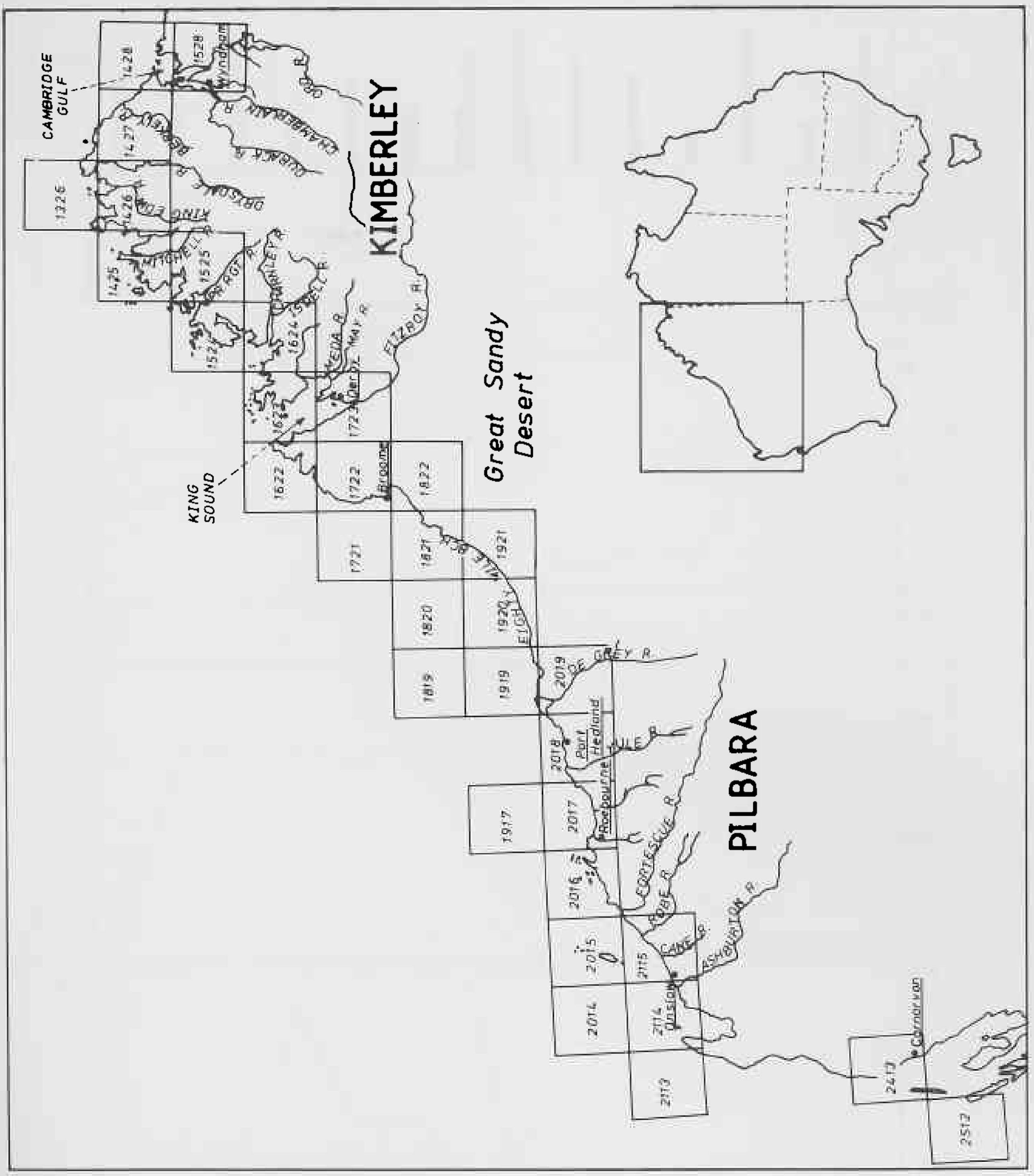

Fig. 1. Location of fishing blocks, rivers and ports for the Western Australian barramundi fishery.

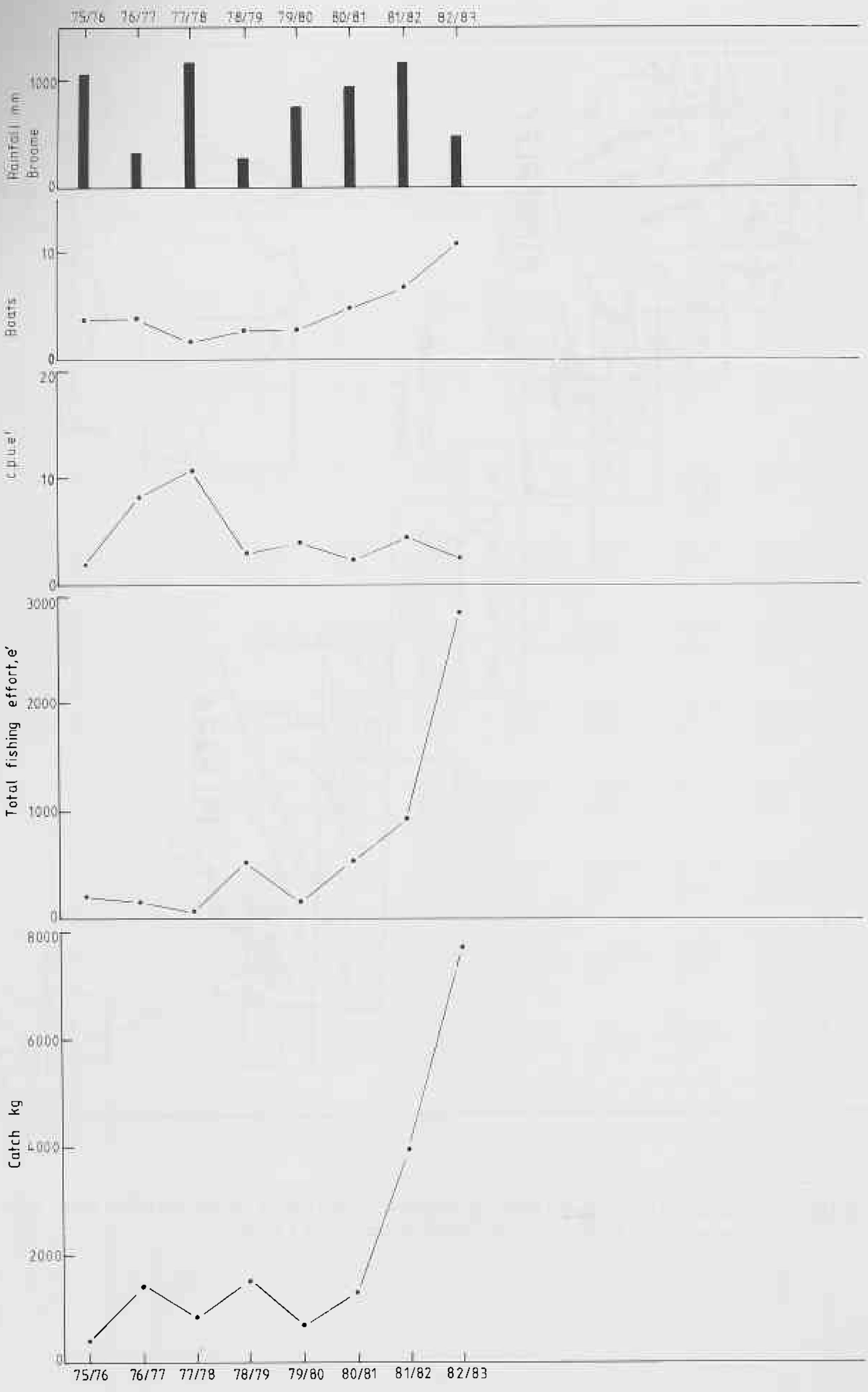

Fig. 2. Statistics for the Broome coast.

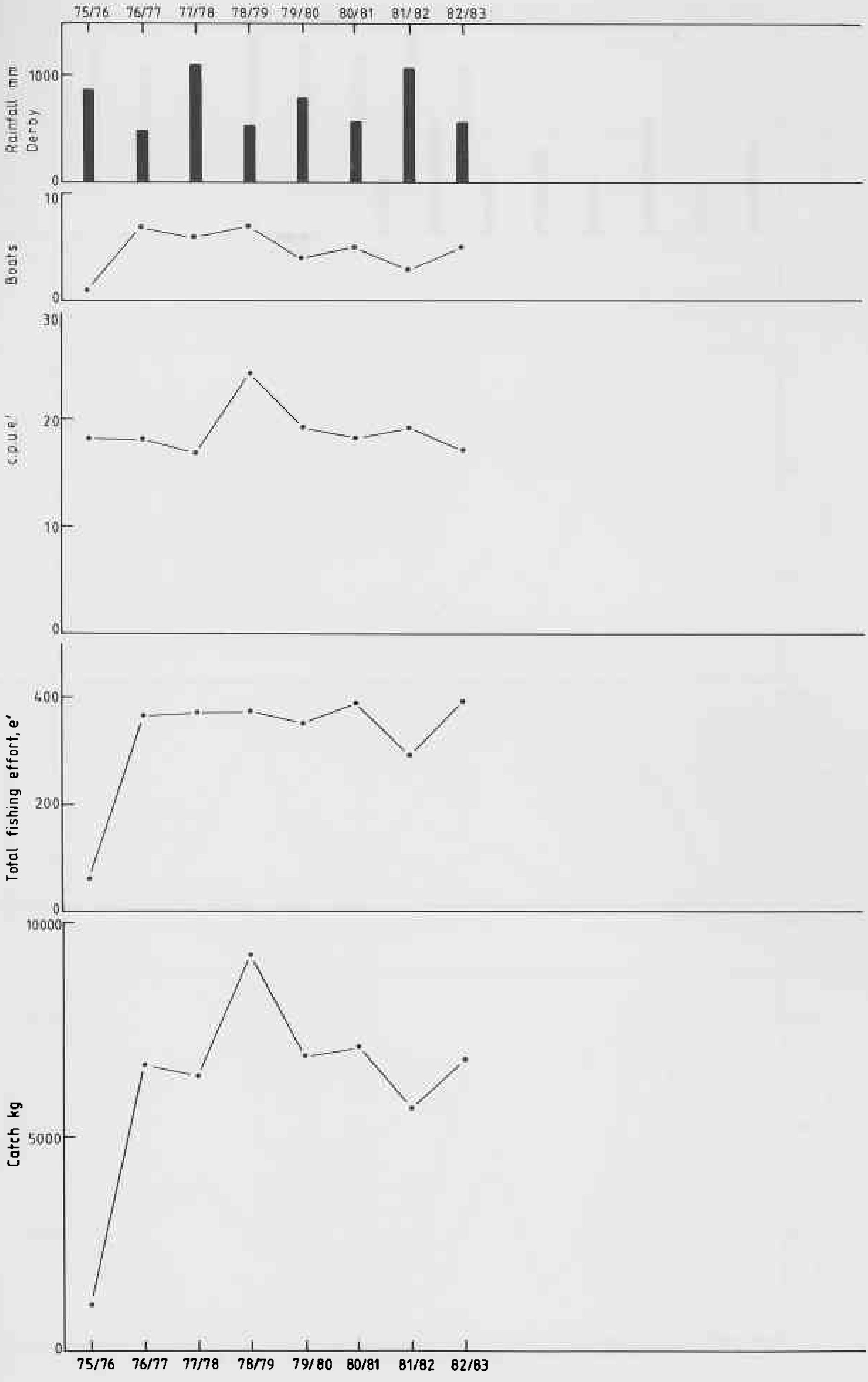

Fig. 3. Statistics for the Fitzroy River.

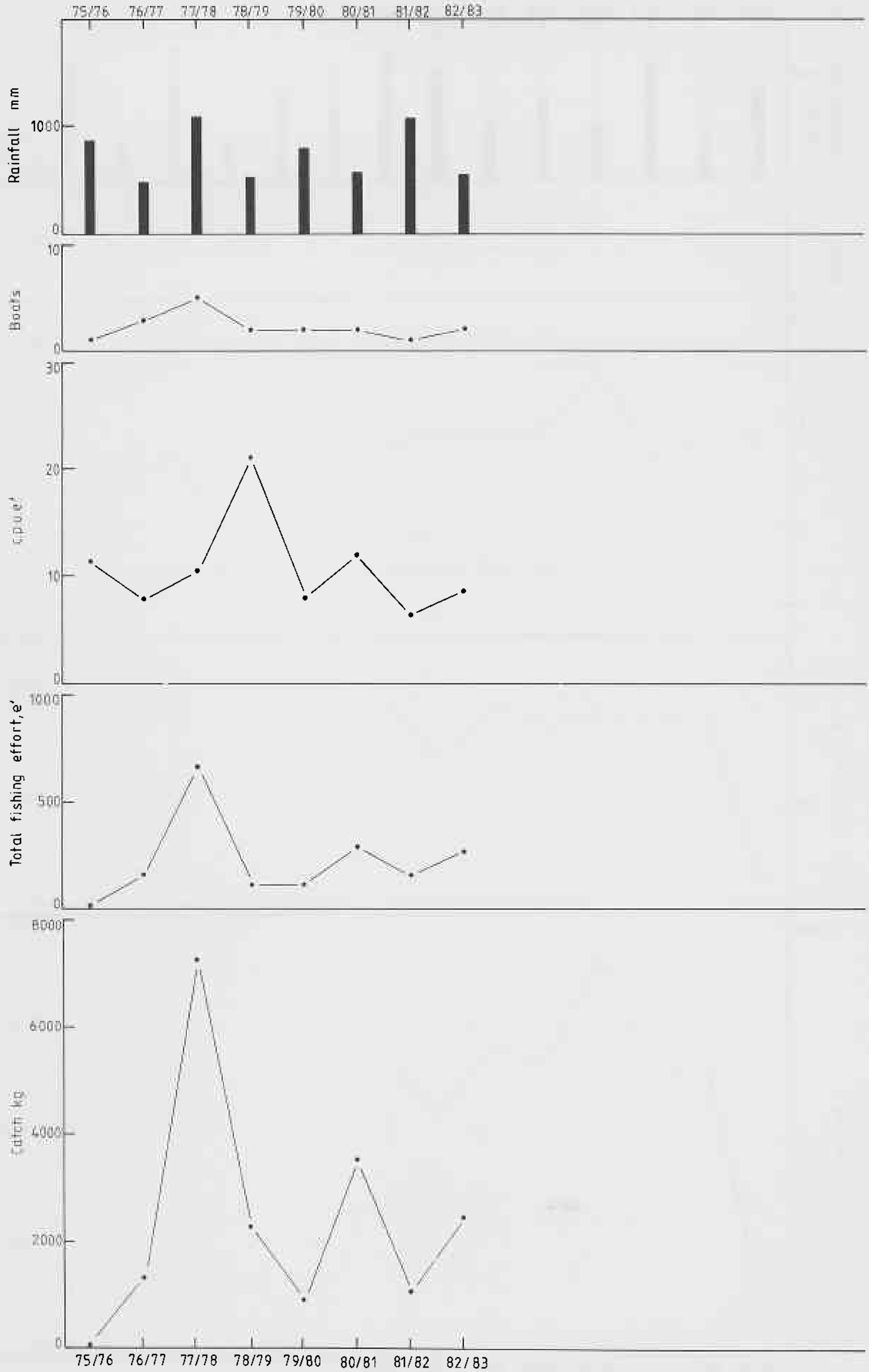

Fig. 4. Statistics for Outer King Sound.

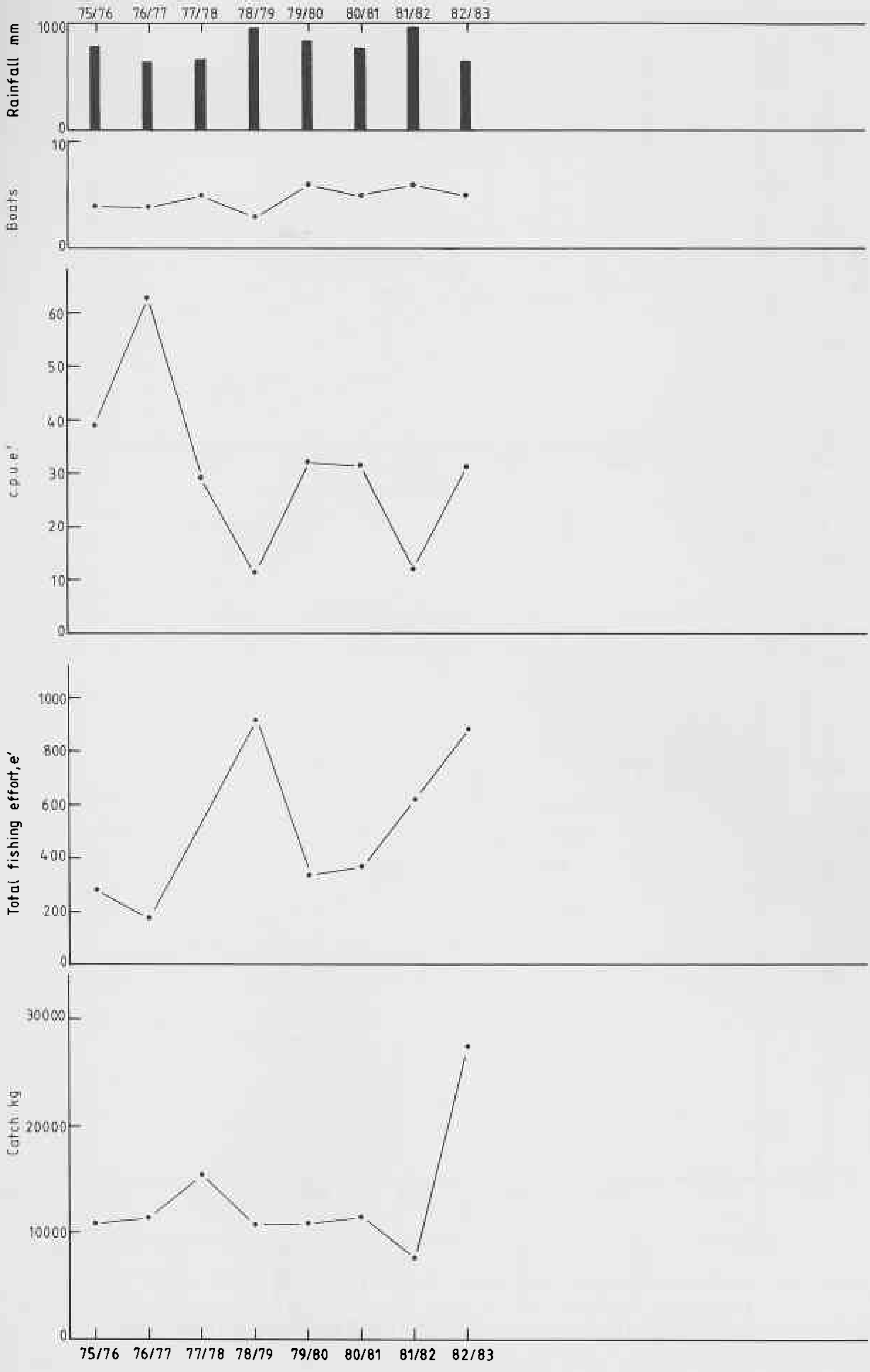

Fig. 5. Statistics for Cambridge Gulf.

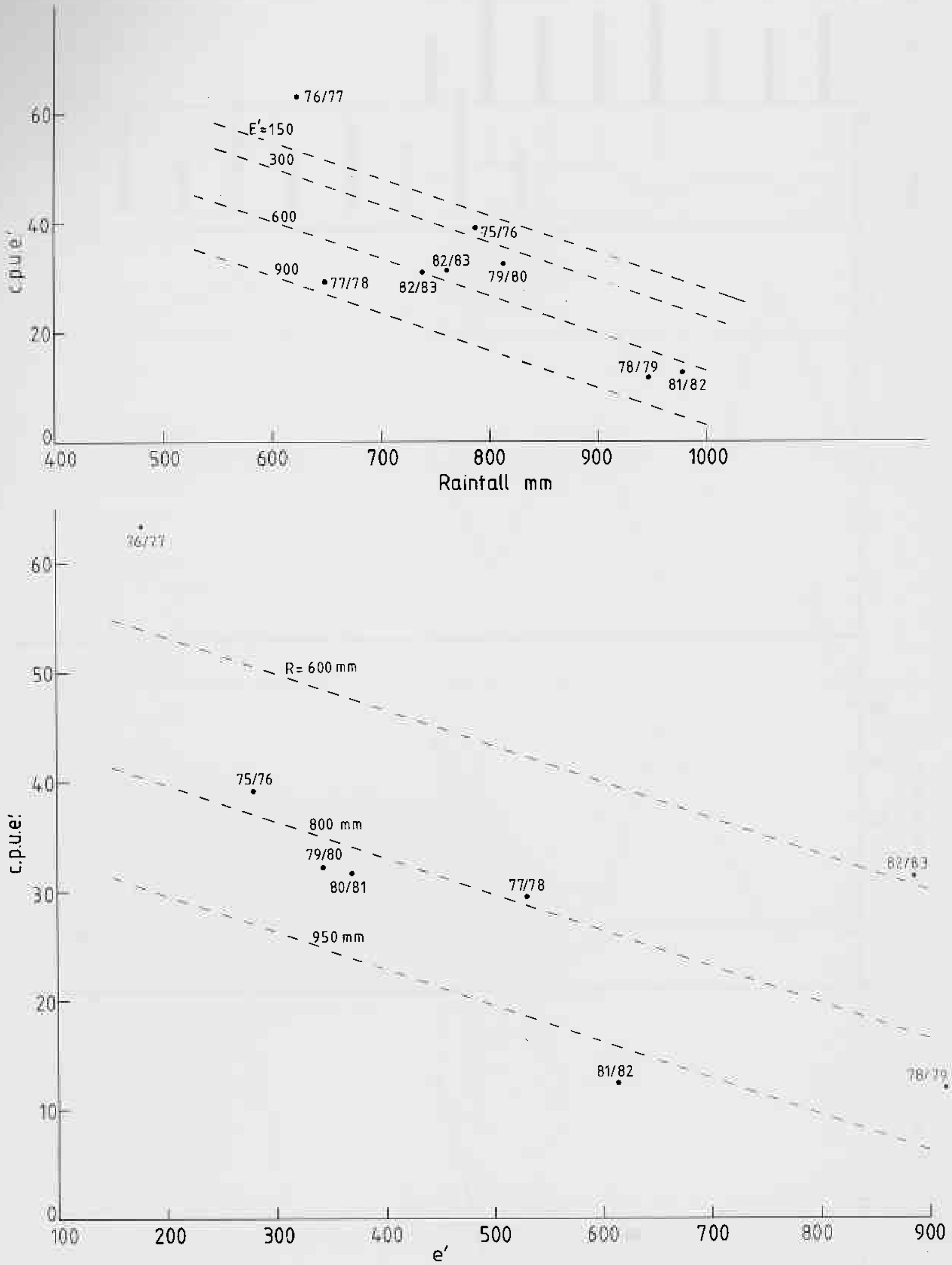

Fig. 6. Relationships between annual catch per unit of fishing effort (c.p.u.e'.), annual fishing effort (e'), and annual Wyndham rainfall for Cambridge Gulf.

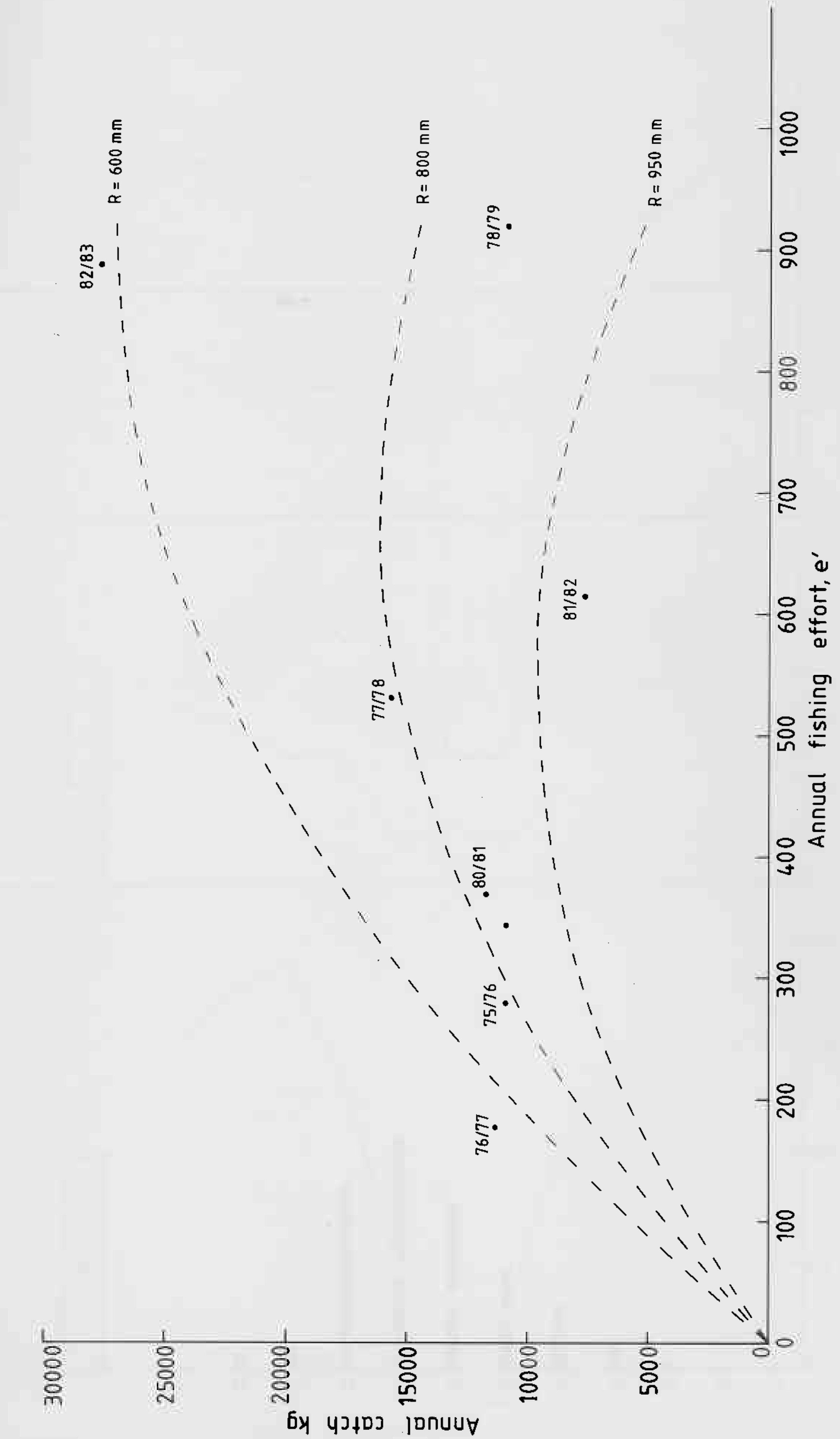

Fig. 7. The catch/effort relationship for Cambridge Gulf with calculated curves for different levels of annual rainfall.

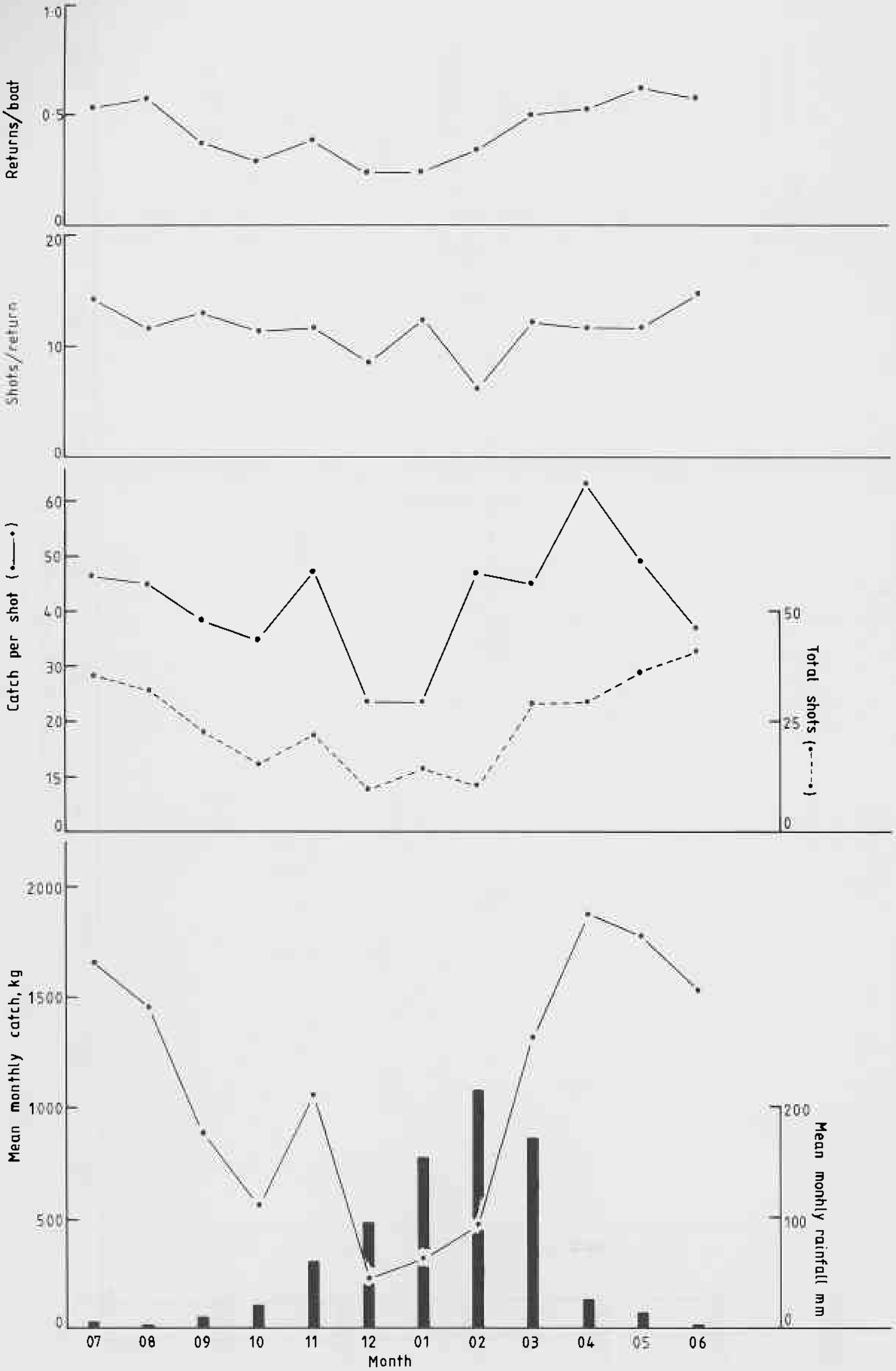

Fig. 8. Monthly catch and fishing effort statistics for Cambridge Gulf in relation to monthly Wyndham rainfall. Mean values for 8 years of fishing.