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CANADIAN THESES ON MICROFICHE / THÈSES CANADIENNES SUR MICROFICHE

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TITLE OF THESIS/*TITRE DE LA THÈSE* The South Australian Prawn Fishery: A Case Study of Limited Data Regulation.

UNIVERSITY/*UNIVERSITÉ* Simon Fraser University

DEGREE FOR WHICH THESIS WAS PRESENTED/*GRADE POUR LEQUEL CETTE THÈSE FUT PRÉSENTÉE* Master of Arts

YEAR THIS DEGREE CONFERRED/*ANNÉE D'OBTENTION DE CE GRADE* 1979

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DATED/*DATÉ* 19 December 1978 SIGNED/*SIGNÉ*

PERMANENT ADDRESS/*RÉSIDENCE FIXE* [redacted]

NL-91 (3-74)

THE SOUTH AUSTRALIAN PRAWN FISHERY: A CASE STUDY OF LIMITED ENTRY REGULATION

by

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B.Ec.(hons.), University of Adelaide, 1974

A THESIS SUBMITTED IN PARTIAL FULFILLMENT OF
THE REQUIREMENTS FOR THE DEGREE OF
MASTER OF ARTS
in the Department
of
Economics and Commerce

SIMON FRASER UNIVERSITY

December 1978

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Degree: Master of Arts

Title of Thesis: The South Australian Prawn Fishery: A Case Study of Limited Entry Regulation

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ABSTRACT

The prawn fishery in South Australia has, since its inception in the late 1960's, been subject to limited entry regulation. It has, as a result, avoided the over-exploitation problems normally associated with common property fishery resources. No attempt, however, has yet been made to estimate the economically most efficient levels and methods of exploitation of the prawn stocks. In addition, the wealth and efficiency implications of the current practice of allowing operators to retain all resource rents have not been fully considered. This thesis attempts to shed some light on each of these matters.

Bionomic models for each stock in the fishery were constructed based on the fitting of surplus yield production functions to observed catch and effort levels. This included development of methods to standardise effort for changes in fishing unit characteristics and seasonal patterns of fishing.

Analysis suggests that adjustment of the current number of licenced operators in each region is unlikely to significantly increase levels of economic rent, but that operator efficiency and the rent level in the Gulf St. Vincent region would be increased by the removal of the current ban in the region on use of double rig. The very high levels of rent retained by operators at present appear to have an adverse effect on

operator efficiency and are also difficult to justify on equity grounds. A progressive royalty rate based on the value of the yearly catch is considered to be the most feasible method for diverting some rents to the public purse.

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A. INTRODUCTION

The economic theory of the exploitation of common property fishery resources has become widely known since the subject was first elaborated in seminal articles by Gordon (1954), Scott (1955) and Crutchfield (1956). It is now generally accepted that in order to obtain resource rents from a fishery, access to the stock must be carefully regulated.[1]

Most of the fisheries of the world have traditionally been open entry, hence discussion to date has centred largely on ways to achieve effective management control. The move of countries to a two hundred mile Exclusive Economic Zone (EEZ) has placed most fisheries within the jurisdiction of single countries, providing the mechanism for rational management.[2] However, there are a large number of socio-political difficulties in implementing limited entry programs and reducing effort levels in historically unregulated fisheries. Few such fisheries have yet reached the position of yielding significant resource rents.

In a fishery which has been traditionally open entry, fishing effort is normally greater then that which would maximise its economic surplus. For such a fishery, the desirable

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[1]The conventional analysis is well outlined in Anderson (1977b).

[2]See Copes (1977) and Anderson (1977a) for a discussion of implications of the unilateral declaration of the two hundred mile EEZ.

direction of effort adjustment can therefore be deduced directly from the fact that entry has been unrestricted. Policy initiatives in this area can therefore precede detailed consideration of the peculiarities of the specific fishery. Few estimates of the relationship between resource rent and fishing effort for particular fisheries have been made.[1]

Little attention has been given to the desirable distribution of the resource rents generated by an effective management program and how it could be achieved in practice. This is considered a question which can be approached after the goal of effort reduction has been realized. Even then it may be of little consequence if the possible rents are small relative to the costs of exploitation. Where rents have been generated, they have been retained by fishermen in the absence of any definite consideration of the possible alternatives.

The prawn fishery of South Australia did not follow the usual pattern of development refered to above. Although yearly fishing effort has increased continuously since the late 1960's when exploitation commenced, entry of vessels to the fishery has been restricted at all times. The characteristics of each vessel have also been strictly regulated. As a result, fishing effort

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[1]A large amount of research has been concerned with the nature of of the yield-effort relationship for particular fisheries, however this is only one of a number of inputs into a total economic model. Major contributions in this area include Beverton and Holt (1957) Ricker (1975), and Schaefer (1954).

has been held below the open entry level. To this extent, the management of the resource has been superior to that of all but a few of the fisheries of the world. Byrne and Harding (1976, 50) also suggest that considerable resource rents are currently being earned by individual operators in the fishery. This results from low capture costs relative to the high unit value of the species being exploited.

It follows that estimation of the relationship between effort and resource rent and consideration of how the benefits of the limited entry program should be distributed have much greater immediate relevance than usual. Unlike the case of a well established open fishery, the assessment of the effect on overall rents of increases or decreases in aggregate effort depends on a knowledge of the relationship between effort and resource rent for this particular fishery. The size of the profits currently being earned by operators also suggests that direct consideration of the justification for and implications of full rent retention by fishermen and the alternative allocation possibilities is necessary.

As yet, none of these matters has been directly considered by the South Australian Government, which is responsible for current regulations. This study will attempt to shed some light on these areas and so suggest further improvements to what is already a relatively advanced management program.

The prawn species which is exploited in the fishery has three characteristics which make the study of particular interest. Firstly, because it is extremely fecund it is considered to be non-self-regulating in that the level of regeneration from a given spawning season is largely independent of the size of the parent stock. Secondly, its short adult life span leads to the exploitation of chiefly a single year class at a time. Thirdly, its very seasonal regeneration pattern results in a marked seasonal abundance cycle.

The study begins with basic basic background information on the South Australian prawn fishery. This includes descriptions of the historic pattern of development and the regulations which have been imposed by the South Australian Government, the nature of the fishing operation and the biology of the exploited species.

The methods applied in previous studies to estimate the economic yield from a fishery are then reviewed and their applicability to a prawn fishery, assessed. Methods of adjustment to take account of changes in the seasonal effort pattern and the heterogeneous nature of the prawn fleet are also developed. Suitably modified models are then used to draw broad conclusions concerning what appear to be desirable adjustments in the level and manner of exploitation for each stock in the fishery. Very rough estimates of the relative economic rents which exploitation of each stock is generating and possible rent increases are also made.

This is followed by a discussion of the efficiency and wealth implications of various possible methods of distributing access rights and economic rents in a limited entry fishery and their relevance to the fishery under consideration. An outline of what is considered to be a viable scheme for distributing access rights and resource rents for the South Australian prawn fishery concludes the study.

B. BACKGROUND NOTES ON THE SOUTH AUSTRALIAN PRAWN FISHERY

I. THE JUSTIFICATION FOR REGULATION OF FISHERIES

Before considering the major features of the South Australian prawn fishery and its management, a very brief review of the justification for public management of fisheries is worthwhile.[1]

A significant feature of almost all fisheries is the common property nature of the resource. A fisherman cannot exclude any other operators or obtain compensation for any reduction in the benefits he receives as a result of other operators' activities. It follows that an individual operator is unable to fully capture the benefits which may result from any enhancement or conservation measures which he undertakes. There is therefore no incentive for him to indulge in such activities even though their value may significantly exceed their cost from the viewpoint of the fishery as a whole. By similar reasoning he is unlikely to take into account any of the undesirable consequences for other participants of his own operations.

Whilst not exhaustive, the following illustrate the types of negative externalities which the fishing operations of a

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[1] A reasonably complete discussion of the conventional arguments together with an extensive bibliography is given in Anderson (1977b).

given unit may generate.[1]

1. Its fishing reduces the size of the fish stock. This may reduce the rate of reproduction of the stock and hence the size of the future fish stock and therefore the catch rate from exploitation of this latter stock.

2. Its fishing reduces the size of the fish stock and hence the catch rate from exploitation of this residual stock.

3. Its use of particular types of gear or fishing methods may reduce the size of particular segments of the stock and therefore the catch rates from exploitation of these segments.

4. Its presence in a particular area may, because of the uneven distribution of the stock, reduce the catch rate of concurrently operating units.

In an open entry fishery, each fishing unit will increase its level of fishing until it is earning a normal rate of return at the margin. But because of negative externalities such as those above, its marginal unit of fishing effort is generating a negative social return.

Public management of the fishery is able to bring about an allocation of resources which takes into account these negative externalities. It can, as a result, significantly improve the social welfare contribution of the fishery.

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[1]Some of these are discussed in Pontecorvo et al. (1977) or Smith (1969).

II. DEVELOPMENT OF THE FISHERY AND ITS REGULATION

There is no one generally accepted definition of what constitutes a fishery. The scope of any study is based on an arbitrarily drawn boundary. This thesis will focus on the primary sector of the South Australian prawn fishery. No primary fishing enterprises in South Australia are permitted to carry out processing of their catch,[1] hence the above boundary means that only aspects of the actual fishing operation will be considered.

Commercial exploitation of prawn stocks of the coast of South Australia commenced in late 1967 after a number of previous unsuccessful attempts.[2] Initially, trawling was confined to Spencer Gulf, but grounds were soon discovered in Gulf St. Vincent and on the West Coast. In 1975, new grounds began to be fished in Investigator Strait. All these areas are shown in Figure 1.

In order to achieve controlled development of the resource, in March 1968 the Government of South Australia closed entry and allowed only those operators issued with prawn trawling permits

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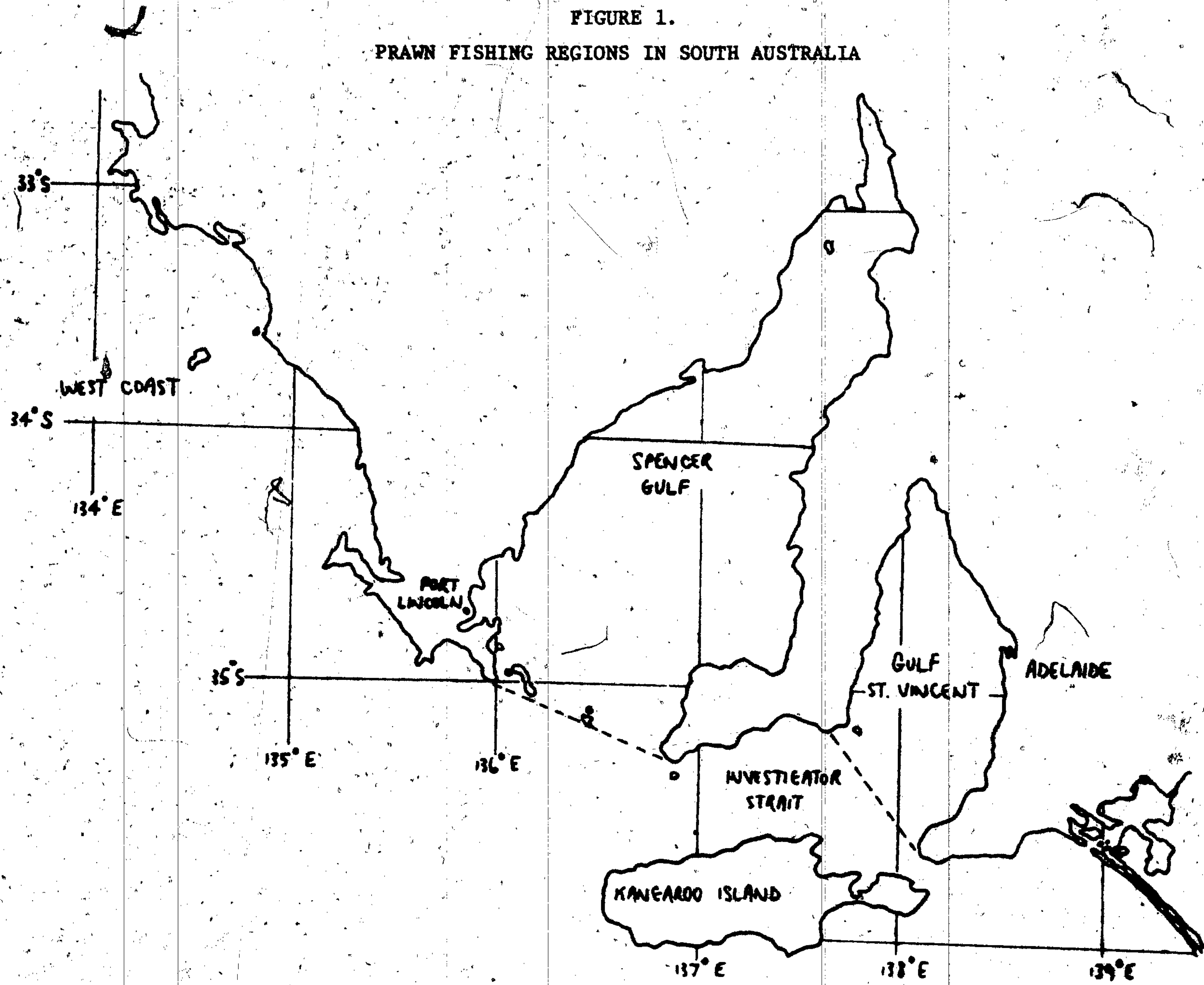
[1]As at 1977, one prawn fisherman was processing on board his vessel, but the prohibition has otherwise been effective. See SAFIC (Aug. 1977, 30)

[2]The early history is described in Olsen (1975, 234-35) and King (1978, 41-42).

FIGURE 1.

PRAWN FISHING REGIONS IN SOUTH AUSTRALIA



to participate in the fishery. Since the introduction of "the Preservation of Prawn Resources Regulations" in April 1969, the Government has issued more permanent prawn trawling authorities.[1] In addition, small numbers of temporary Ministerial Permits have continued to be issued at various times, often to explore possible new areas.

Given the importance of licencing arrangements in the overall management of the fishery, it is worthwhile to elaborate on some of the features of a prawn trawling authority or permit. An authority is held in perpetuity by an operator, subject to the payment of a nominal[2] licence fee and acceptance of any conditions imposed by the management authority.[3] Permits are temporary, being issued for only six monthly periods at a time, and having no automatic right of renewal, but otherwise carry the same access rights as authorities. Although the authority or permit is assigned to an individual or partnership, the holder must also nominate and have authorised, the vessel to be used for prawn trawling.

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[1]The term 'authority' is equivalent to the more conventional 'licence'. The terms will be used interchangeably throughout the study.

[2]In September 1978 a move towards substantial licence fees was made by the South Australian Government. The position on this issue is currently under discussion.

[3]These will be elaborated on below.

Officially, access rights are non-transferable, with the government being free to reassign discontinued licences as it wishes.[1] However in practice this policy has been ineffective because the Government has automatically reassigned authorities to the purchasers of authorised vessels. Up until 1973 this was done via the transfer of the existing authority to the vessel purchaser, but, following arguments as to the legality of this practice,[2] the current procedure of issuing a new authority to the buyer of the authorised vessel was adopted.[3] Both methods effectively attach the authority to the vessel rather than the individual.

A potentially crucial requirement governing sales of authorised vessels is that the price must be considered by the Government to be the fair market value of the vessel and its equipment without an associated authority. However, as yet no prices submitted for approval have been disallowed. In addition, there is no guarantee that the official and actual prices correspond.[4] Under-the-table payments above the official price would be very difficult to detect and are also rational from both a buyer's and seller's viewpoint.

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[1]See Copes (1978, 123) and Byrne and Harding (1976, 67).

[2]See Olsen (1975, 237-38)

[3]See Byrne and Harding (1976, 67).

[4]The current "unofficial" values of authorities are rumoured to be $100,000 to $200,000.

To this date, no authorities have been voluntarily surrendered without the holder also achieving a transfer via the sale of his authorised vessel.

The procedure for allocation of new authorities or re-allocation of those authorities that have involuntarily lapsed has changed considerably since 1969. Initial authorities were granted to all competent applicants who possessed a vessel suitable for prawn trawling. However, as the profitability of the fishery became established, rationing devices soon became necessary. New authorities were granted to applicants who best met a large number of criteria such as length of service as a fisherman, either as crew on an existing prawn vessel or skipper of a vessel in a less profitable fishery, suitability of the nominated vessel for prawn trawling, location of home port and family involvement in the fishing industry.[1]

The allocation decision was initially made by the Government and later by the Prawn Industry Advisory Committee. Since the disbandment of this Committee in late 1976, new allocations have been based on random selections from a large number of applicants who met very general criteria such as nomination of a suitable vessel and possession of a Class A

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[1]A large number of specific factors which would be considered were detailed in 1974 when the Prawn Industry Advisory Committee was established. These are listed in Byrne and Harding (1976, 67-68).

general fishing licence.[1]

The regulations imposed by the South Australian Government in conjunction with the limited entry scheme have been of three main types:[2]

1. Restriction of the types of entities which may hold an authority or permit.

2. Restriction of the areas in which an operator is permitted to fish.

3. Restriction of the type of fishing unit which may be used.

An owner-operator policy has been strictly enforced since the establishment of the prawn fishery. The authority holder must be on board the authorised vessel during all trawling operations, and may not hold an authority in any other limited entry fishery. The motive for this policy has presumably been a desire on the Government's part to ensure that working fisherman rather than other groups receive the benefits of the limited entry programme.

In the years 1968 to 1970 several authority holders for the West Coast and Spencer Gulf continued to fish for tuna during its short season from February to May, then undertook prawn

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[1]The criteria which must be met to hold a Class A general fishing licence are listed in Byrne and Harding (1976, 61-65). In summary a person must be a competent full time professional fisherman.

[2]The administrative policies for managed fisheries in South Australia are summarised in Byrne and Harding (1976, 66-71) and King (1978, 44-48).

trawling for the remainder of the year.[1] After 1970, authority holders were not permitted to take other species and all became full time prawn fishermen.[2]

To avoid an excessive concentration of fishing on the best grounds, each operator has normally been confined to only a part of the total fishery. Fishermen were initially authorised to fish in one of three regions only, on the West Coast, the Spencer Gulf or the Gulf St. Vincent. In 1971 the division between the West Coast and Spencer Gulf was removed, creating two separate fleets. A third fleet has developed recently with the exploitation of the new Investigator Strait grounds. These areas are shown in Figure 1.

Table I lists the number of operators in each fleet on a yearly basis and the number of authority transfers which have occurred via sales of authorised vessels. It can be seen that the number of participants has increased steadily in both main fleets with the Spencer Gulf fleet being roughly three times as large as that of Gulf St. Vincent. The numbers of transfers have been approximately proportional to the numbers of authorities on issue in each fleet. As yet, only ministerial permits have been issued for Investigator Strait.

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[1] See Australia, Fisheries Division, Australian Department of Primary Industry (1974).

[2] The sale of accidental by-catch taken during trawling is however permitted to a limited extent.

TABLE I

NUMBER OF AUTHORITIES AND PERMITS ON ISSUE AND NUMBER OF SALES OF AUTHORISED VESSELS BY FLEET FOR YEARS 1968 TO 1977

Year	West Coast and Spencer Gulf		Gulf St. Vincent		Investigator Strait		Total	
	No. on[1] Issue	No. of Sales	No. on Issue	No. of Sales	No. on Issue	No. of Sales	No. on Issue	No. of Sales
1968	22	-	3	-	-	-	25	-
1969	28	1	4	-	-	-	32	1
1970	30	-	8	-	-	-	38	-
1971	35	1	10	-	-	-	45	1
1972	36	2	10	1	-	-	46	2
1973	36	3	10	-	-	-	46	3
1974	40	3	12	-	2	-	54	3
1975	40	4	12	2	5	-	57	6
1976	42	4	14	2	5	-	61	6
1977	42	2	14	-	5	-	61	2

Source: Files of Department of Agriculture and Fisheries, South Australian Government.

1 The maximum number of concurrently issued authorities and permits during each year was used, to avoid double counting of reissued authorities or permits.

To protect prawns of a non-commercial size from capture, all waters of less than ten metres depth are closed to trawling, whilst certain other areas also inhabited by small prawns are subject to either seasonal or total closure. For similar reasons, a minimum mesh size for trawl nets is also specified.

Restrictions on vessel size and type and size of rig have also been gradually introduced to restrict the fishing effort of individual vessels. Vessels operating in Gulf St. Vincent have been generally confined to single rig[1] and a maximum length of 14 metres. In July 1974 a 17 metre vessel length restriction was also imposed for replacement vessels in the West Coast-Spencer Gulf fleet.

In addition, a maximum net headline length, based on boat length, was introduced, for all regions, in order to limit the effort which could be exerted by a specific vessel. The formula is

$$H = 17 + .882L$$

where:

H = Maximum headline length in metres

L = Vessel length in metres.

In December of the same year the lengths of replacement vessels were further constrained by requiring that, in addition to the above absolute limits, they be no greater than those of

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[1] Double rig was allowed for a brief period in 1974 to 1976, but was not adopted by any vessels.

the vessels they replaced. The hull of the existing vessel also had to be in a condition such that it would be scrapped on the replacement vessel coming into operation.

Some elaboration is also necessary concerning jurisdiction over the fishery. In August 1976 it was decided that in fact a small part of the Investigator Strait fishing region was within Commonwealth of Australia rather than State waters.[1] This area was then declared a managed fishery by the Commonwealth Government. It has authorised a number of vessels, including all those previously operating in the area, to trawl in these waters. Discussions aimed at joint management, in this area are currently under way.[2] The major part of the fishery is still, however, under State Government jurisdiction.

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[1] Decision of the High court of Australia August 1976.

[2] See SAFIC (Nov. 1976, 8, Aug. 1977, 4-5, Nov. 1977, 47-48 and Aug. 1978, 2.)

III. BIOLOGY OF THE SPECIES

The South Australian prawn fishery is based on exploitation of adult stocks of a single species of penaeid prawns (*Penaeus latisulcatus*) commonly known as the Western King Prawn.[1] Biological research on South Australian stocks is by no means complete. However their life cycle appears to be very similar to that of the same species which is fished in Shark Bay, Western Australia. It is likely to follow the typical penaeid shrimp pattern, which suggests the following life cycle.[2]

Spawning occurs chiefly in early summer, from November to January, with each mature female releasing extremely large numbers of fertilized eggs directly into areas occupied by the adult prawns. They remain there in a planktonic form for two to three weeks then move into shallows and estuaries as juveniles. After feeding and growing in these nursery areas for up to twelve months the young adults gradually re-enter deeper waters in December to February. Females may first spawn soon after leaving the nurseries, and spawning is repeated on a yearly basis until death.

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[1]See Olsen (1975).

[2]For a detailed outline of the biology of penaeid shrimp see Rounsefell (1974, 346-49). The biology of the Western King Prawn in Western Australia and South Australia is described in Walker (1975) and King (1978) respectively.

The prawns become vulnerable to capture, usually referred to as the point of recruitment, soon after re-entering deeper waters. The average lifespan of individuals will depend on the level of fishing. At moderate effort levels such as those in South Australia, it is considered that the majority of prawns are either captured or die from other causes within a year of leaving the nursery areas, although survival for over two years has been observed in some cases.[1]

Because of their extremely high fecundity and the fact that pre-recruitment mortality is very density dependent, the level of recruitment for most prawn stocks is generally considered to be independent of the parent stock size at normal levels of exploitation.[2] King (1978, 100) argues that this is also the case for the South Australian prawn stocks. The level of recruitment is instead influenced by various environmental factors.[3] There are considerable random fluctuations in the yearly recruitment levels caused by variations in these latter factors.

Since prawns are subject to capture for a period of less than one year on average, and recruitment is concentrated in a

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[1]The levels of natural and fishing mortality are discussed at length in King (1978, 115-130).

[2]See for example Anderson (1977b, 23 and 103), Griffin et al. (1976,247), Neal (1975, 3-4), Rounsefell (1974, 261-263) and Walker (1975).

[3]See King (1978, 100).

small part of the year, largely a single year class of recruits is exploited at a time.

As a result, there is little relationship between the level of fishing in one year and the stock levels in subsequent years. The high rate of mortality in the period after the annual entrance of recruits to the fishing grounds also means that there is a marked seasonal abundance cycle.

In South Australia, adult prawns are abundant in certain areas on the West Coast, Spencer Gulf, Gulf St. Vincent and Investigator Strait, as shown in Figure 1. The major juvenile areas are the northern parts of both gulfs and Venus Bay on the West Coast.

IV. THE FISHING OPERATION AND STRUCTURE OF THE FLEET

Fishing is undertaken using the otter trawl technique as perfected in the Gulf of Mexicc shrimp fishery.[1] This essentially consists of towing a synthetic net (or nets) over the sea bottom behind the vessel. Trawling is generally undertaken at night and extends for up to eleven hours, with each shot taking from thirty minutes to two hours. After each shot the catch is emptied from the nets onto the decks and the prawns are separated from the rest of the catch. They are then stored in large built-in refrigerated brine tanks or in freezers. At the conclusion of each fishing trip, the catch is off-loaded at suitable ports adjacent to the grounds and transported by road to processing factories in ice-chilled bins.[2] Major home ports are Pt. Lincoln and Pt. Adelaide.

There is considerable variation in the type of vessel operating in the fishery. Many of the initial vessels were converted tuna or rock lobster vessels. Later entrants have largely been designed especially for prawn trawling, either being built for the South Australian fishery cr coming from the large Gulf of Carpenteria prawn fleet. Hulls are constructed of

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[1]This is described in detail in Knake et al. (1958).

[2]The fishing operation is described in much greater detail in King (1978).

either timber or steel. Vessels usually have the wheelhouse and accommodation forward leaving a clear working deck for sorting of the catch, which is then stored below deck.

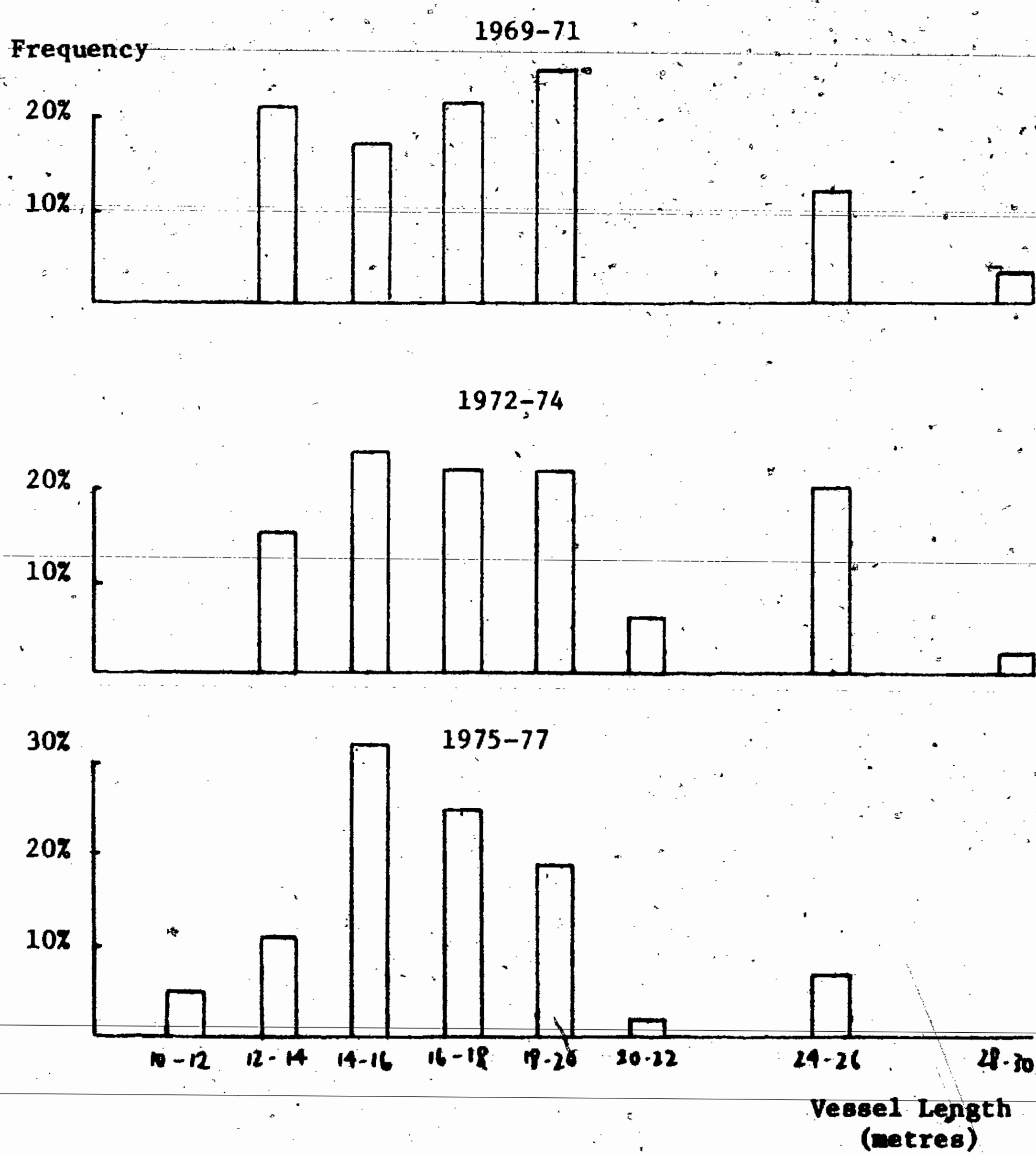
Catch storage facilities are of two basic types, refrigerated brine tanks and dry freezers. As discussed by Ruello (1975, 192-201), prawns stored in refrigerated tanks suffer serious deterioration in quality after two to three days, due to both physical and chemical changes. Frozen prawns, however, keep indefinitely without significant quality decline. Brine tanks are used by almost all the smaller and most of the intermediate sized vessels and limit fishing trips to one or two nights. Freezing facilities are available on the largest and a number of intermediate sized vessels, which allows their trips to extend until a full load is taken, up to four or five nights, depending on the catch rate.

Vessels operate independently, and all are equipped with echo-sounders to assist in the location of suitable trawling areas.

There has always been a large range in the lengths of vessels operating in Spencer Gulf, with extremes of twelve and twenty-nine metres. A length frequency distribution for each of the periods 1969-71, 1972-74 and 1975-77 is given in Figure 2. There has been a gradual standardization over the last few years but this has been hampered by the restrictions on size of replacement vessels outlined in Section B.II. In Gulf St.

FIGURE 2.

RELATIVE FREQUENCY DISTRIBUTIONS OF VESSEL LENGTH
FOR WEST-COAST SPENCER GULF FLEET



Vincent on the other hand, vessels have always been very uniform in size, almost all being in the twelve to fourteen metre range.

Average lengths of vessels have remained relatively stable over time, with the West Coast-Spencer Gulf fleet having a mean of about seventeen metres whilst the Gulf St. Vincent boats have been considerably smaller with an average of about twelve and a half metres. Average vessel lengths for all fleets for each year are given in Table II.

Both single and double rigs are used in the fishery. Double or twin rig consists of a pair of matched nets side by side, whilst single rig consists of a single larger net. Initially double rig was used only by the larger vessels, but it has by now been adopted by all but a few of the smallest boats in the Spencer Gulf fleet. Although the restriction to single rig in Gulf St. Vincent was lifted between 1974 and 1976, double rig has never been adopted by any of the vessels operating in this region. The percentage of vessels using double rig by year and region is given in Table II.

Brake Horse Power (BHP) of engines of vessels have been closely related to vessel lengths in any given year. However, the average horsepowers for given vessel lengths have increased substantially over the last ten years. This is reflected in the significant yearly increases in average engine powers for both main fleets despite relative stability of average vessel lengths. The smaller (under fourteen metre) single rig vessels

TABLE II

AVERAGE VESSEL LENGTH AND BHP AND PERCENTAGE OF VESSELS USING DOUBLE RIG BY FLEET FOR YEARS 1968 to 1977[1]

	West Coast/Spencer Gulf			Gulf St. Vincent			Investigator Strait		
	L(m)	BHP	D. Rig(%)	L(m)	BHP	D. Rig(%)	L(m)	BHP	D. Rig(%)
1968	17.0	166	24.1	12.3	103	0	-	-	-
1969	18.0	183	30.0	12.7	91	0	-	-	-
1970	18.1	181	43.8	12.6	100	0	-	-	-
1971	18.0	194	43.0	12.4	112	0	-	-	-
1972	18.1	228	44.4	12.4	132	0	-	-	-
1973	18.0	231	52.8	12.5	141	0	-	-	-
1974	17.3	253	58.5	12.9	148	0	-	-	-
1975	16.4	248	79.0	12.5	163	0	-	-	-
1976	16.0	245	83.3	12.4	163	0	14.4	171	50
1977	16.4	253	90.0	12.5	159	0	14.4	166	50

Source: Files of Department of Agriculture and Fisheries, South Australalain Government.

[1] Excludes vessels which were authorised for only part of a year.

in Spencer Gulf in general have had slightly less powerful engines than the Gulf St. Vincent vessels which are of a similar size. Average BHP of vessels by year and fleet are shown in Table II.

The number of crew is also closely related to boat size, and varies from two to six persons.

The usual measure of the level of participation by a vessel over a given period is the number of hours spent actually trawling. In all years there have been large differences in hours trawled among vessels, especially within the Spencer Gulf fleet, although the relative number of hours trawled by specific vessels has been relatively stable. In other words if a vessel trawled much less than average in one year it usually also trawled less than average in other years. Frequency distributions of yearly hours trawled by vessels in each of the two major fleets for 1971-73, 1974-75, and 1976-77 are shown in Figures 3 and 4.[1]

Possible explanations for the observed Spencer Gulf spread include differences in vessel and skipper efficiences, physical limits on the periods of fishing of some vessels or variations in the work-leisure preferences of owner-skippers and crews.

Since there is a marked seasonal abundance cycle,

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[1]The years 1968 to 1970 were excluded because a number of vessels were operating on only a part-time basis during this period, for reasons discussed in Section B.II.

FIGURE 3

RELATIVE FREQUENCY DISTRIBUTIONS OF HOURS TRAWLED
BY VESSELS IN WEST COAST-SPENCER GULF FLEET

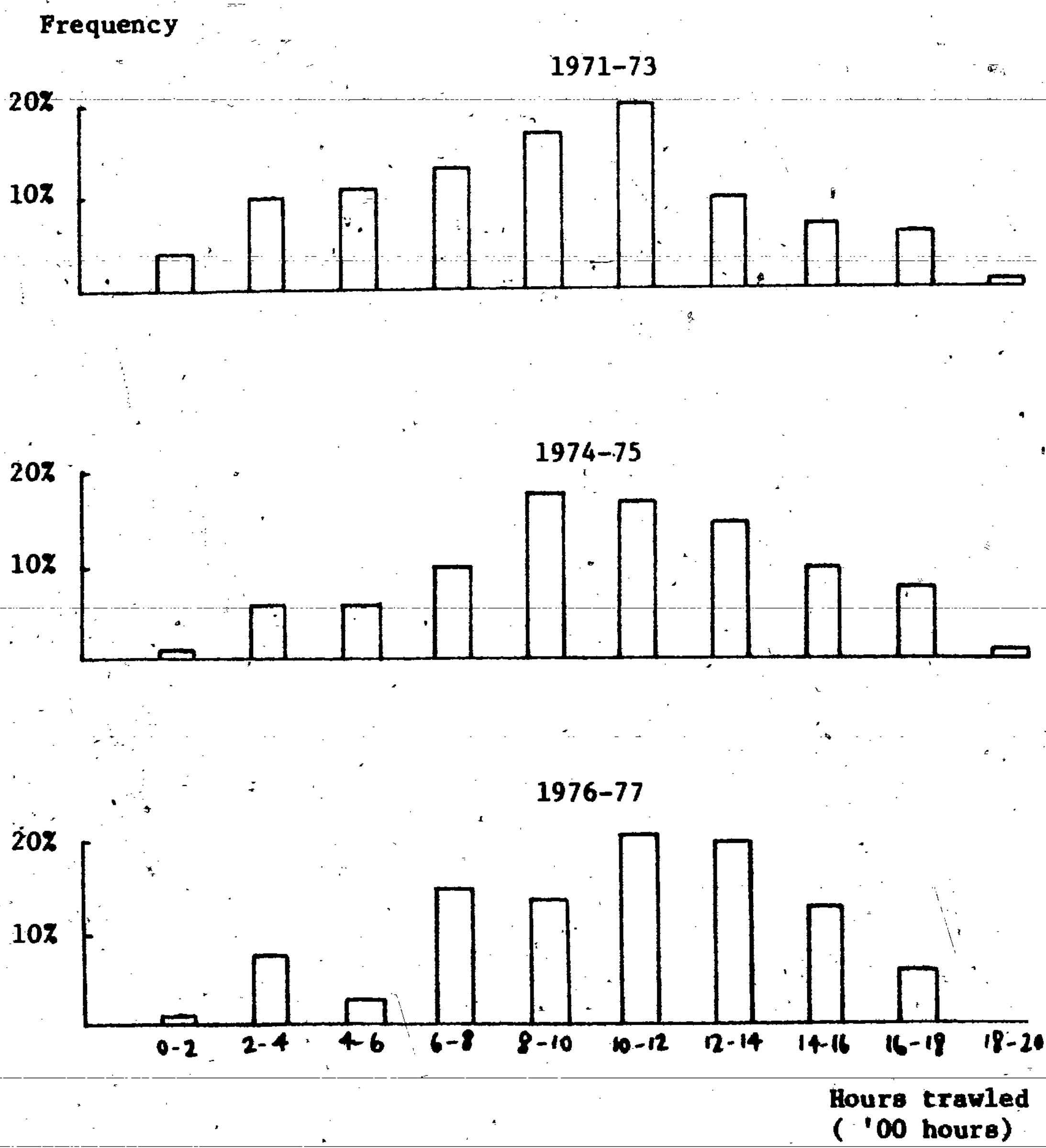
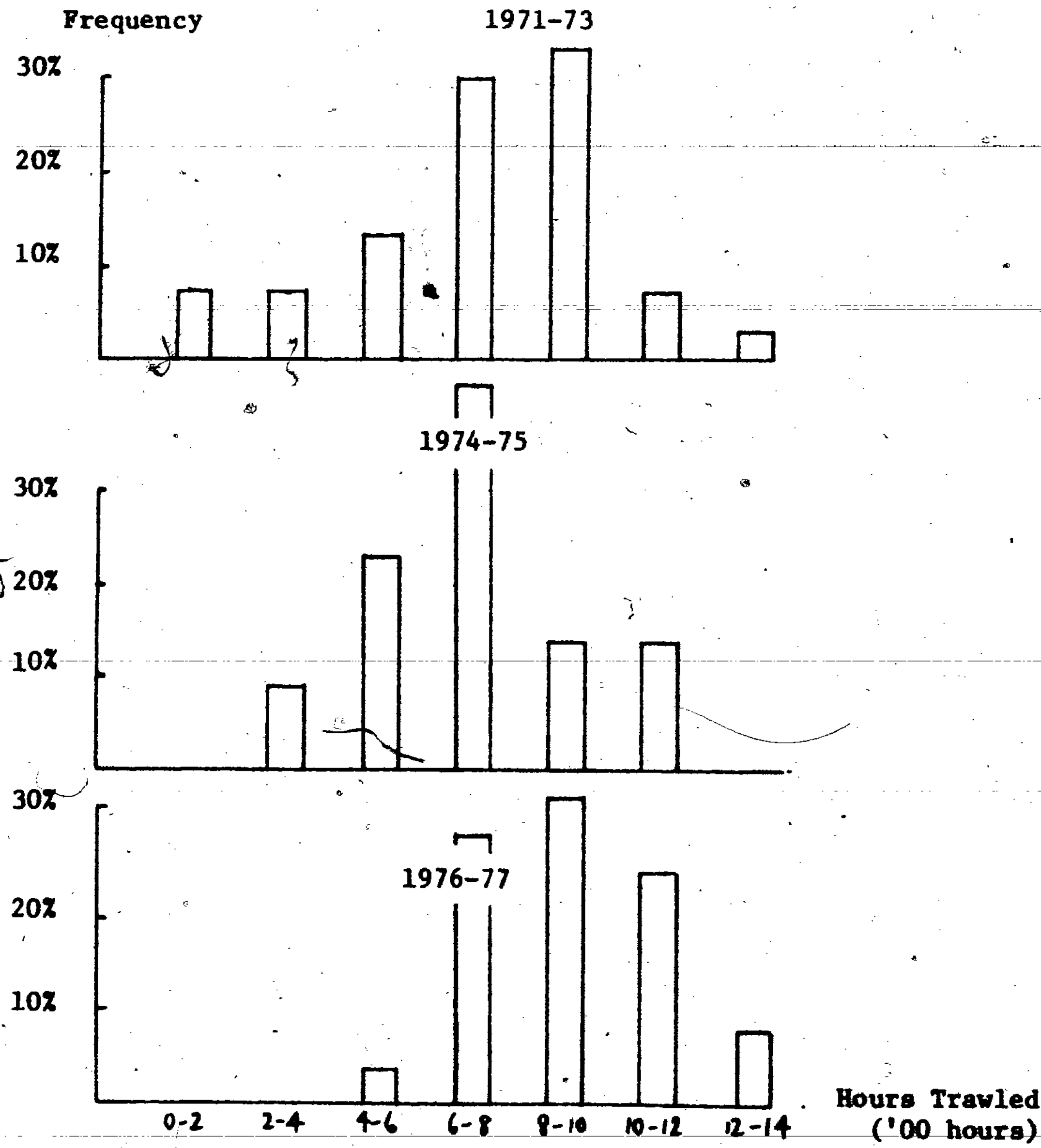


FIGURE 4

RELATIVE FREQUENCY DISTRIBUTION OF HOURS TRAWLED BY VESSELS IN GULF ST. VINCENT FLEET



differences in vessel efficiency (catch, and hence revenue, per unit of cost) could result in a different length fishing season for each vessel if each ceased operations when the catch rate dropped below its break-even point. Ideally one would like to calculate the break even catch rate for each vessel and then check if vessels ceased fishing only when the abundance level dropped below this. Unfortunately the necessary detailed cost data is not available so it was necessary to resort to less obvious checks.

It was considered that if the above hypothesis was correct, vessels operating for only small numbers of hours over a year should fish largely during the peak season, whilst those fishing for longer periods should exhibit a more balanced effort distribution. In other words, a uniform within-year distribution of fishing for all vessels should be unlikely.

To test this, the number of hours trawled by each vessel during the high catch rate months of February to May was regressed against the hours trawled in the remainder of the year for each of the years 1974 to 1977. The equation estimated was

$$TH = a + b\ PH$$

where:

PH = hours trawled by each vessel during the peak-abundance February to May period

TH = hours trawled by each vessel in the remainder of the year.

The results suggested a considerable degree of uniformity, with the PH coefficient being significant at the 99% confidence level in three of the four years. It was therefore concluded that efficiency differences were not the major cause of the observed participation level differences.

An alternative possibility is that smaller vessels fish less because their less sophisticated storage facilities reduce the length of each trip or because they require more favourable weather conditions for safe operation. However a regression of hours trawled per year against vessel length failed to support this hypothesis. In only one of the six years from 1971 to 1977 was the vessel length coefficient positively significant at the 95% confidence level, and even then the explanatory power of the total equation was extremely low.

A final reason for the observed variances could be differences in the target incomes of individual owner-skippers. and crews.[1] Although this could not be tested directly, it was to some extent supported indirectly by the fact that those vessels which had previously been traded consistently operated for longer periods than the rest of the fleet. Purchasers obviously desire higher incomes because of the need to meet the cost of the official purchase price and the likely unofficial

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[1]Note that the requirement that the authority holder must be on the vessel during all trawling operations prevents him from hiring a relief skipper to increase his income whilst holding his hours spent at sea constant.

side payments. The averages were as follows:

	Previously traded (hrs.)	Others (hrs.)
1973	1419	956
1974	1294	868
1975	1160	1091
1976	1231	1036
1977	1153	930

The average yearly number of hours trawled by vessels in both major fleets has steadily increased, as shown in Table III. Note the lower average levels in Gulf St. Vincent. Given the lack of any observed relationship between vessel size and hours trawled within Spencer Gulf and the fact that prawns are considered more abundant in Gulf St. Vincent, the between gulfs difference is unlikely to be explained by either the observed smaller vessel lengths or a shorter season in Gulf St. Vincent.

Again it would appear that operators deliberately refrain from trawling, even though it could be undertaken profitably. They claim that they restrict the total effort so as to avoid overexploitation of the stock.

Whilst the analysis so far has implied that operators in both gulfs do not always attempt to maximize profits in a given period, it is useful to take a somewhat broader view of their behaviour. By deliberately holding down their profit levels, they are probably reducing the likelihood of further new

TABLE III

AVERAGE HOURS TRAWLED PER VESSEL FOR EACH FLEET IN YEARS 1971 to 1977[1]

	West Coast-Spencer Gulf (hours)	Gulf St. Vincent (hours)	Investigator Strait (hours)
1971	744	575	
1972	853	818	
1973	856	804	
1974	845	665	
1975	1117	859	
1976	1102	840	869
1977	1007	724	802

Source: Files of Department of Agriculture and Fisheries, South Australian Government.

[1]Excludes vessels authorised for only part of a year.

licences being issued,[1] an event which could adversely affect their long run profits. Hence they may in fact be attempting to maximize long run profits after all, via adoption of entry forestalling behavior akin to the widely observed monopoly pricing model.

It is concluded that there are considerable differences between the characteristics of individual vessels operating in any one year, and significant changes in the vessel mix have occurred over time. It follows that it will be necessary to express the fishing levels of individual vessels in standard units before meaningful aggregations and comparisons of fishing effort levels can be made.

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[1]The factors affecting the number of licences issued are developed more fully in a later section, but it is clear that the stronger the pressure for more licences, the greater the likelihood they will be issued, and this pressure largely depends on the profit levels of current operators.

V. SEASONALITY OF THE FISHERY

One of the interesting aspects of prawn fisheries is the interaction of the patterns of abundance and fishing effort throughout the year.

For an unexploited fish stock, the number of mature exploitable prawns in a given area is greatest soon after the seasonal influx of new members from the nursery areas. The average size of prawns will move in the opposite direction, being lowest at this time and increasing over the remainder of the adult cycle. Because of high natural mortality, in most cases density is greatest soon after the seasonal increment and declines thereafter.[1] It has also been noted that young adults typically migrate slowly over a number of months away from the nursery areas from whence they came, hence the influx occurs at a later date in areas more distant from them.[2]

For a given level of fishing, the average size of prawns caught, the degree of variation in abundance over the year and the timing of the peak abundance point will all be affected by the seasonal effort pattern and the areas being fished. If fishing is undertaken in the areas adjacent to the nurseries and

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[1]King (1978, 132-33) estimates that the yield per recruit is greatest if prawns are captured at a size slightly below that at which they leave the nursery areas.

[2]See King (1978, 68).

is concentrated in the months immediately following the seasonal exit rate peak, the seasonal abundance fluctuations will be reduced, but the average size of prawns caught will be small. On the other hand, if fishing concentrates on the areas more distant from the nursery areas inhabited by the larger more mature prawns and is more uniform throughout the year, the cyclical changes in density in these areas will be less affected, the average size of prawns caught increased, and the time of maximum abundance will occur later in the year. The abundance levels in the latter areas, however, will be lower on average, because of the greater loss from natural mortality and the greater dispersion of the surviving individuals before they reach such areas from the nurseries.

To examine the within-year effort and abundance cycles within each fishing region, monthly effort and abundance indices could be constructed by dividing the average monthly effort or abundance level within a year into the effort or abundance levels for individual months. That is,

$$Ii = Mi / M \qquad \text{(B.V.1)}$$

where:

Ii = Index for month i

Mi = Effort or abundance level for month i

M = Average monthly effort or abundance level for the calendar year containing month i.

The average level over the calender year containing month i is preferable to the average level over the twelve months centered on month i because of the large random fluctuations in the strength of the yearly regeneration and the correspondence between the natural abundance cycle and the calendar year. The difficulty is to find realistic measures of monthly effort and abundance levels.

The within-year effort distribution of a single vessel in a given region can be calculated from its hours of operation in individual months. However, given the heterogenous nature of the various vessels fishing in each region, one should ideally take into account the differences between vessels before aggregating to provide estimates of the total effort level per month in each region. Unfortunately, only simple aggregates of the hours trawled by all vessels operating in each region were available on a monthly basis in a readily usable form.

Within-year comparisons of these latter totals will, however, give similar results to the correctly weighted sums provided that the vessel mix is stable for all months of the year. In other words it is necessary for the effort patterns of all vessels in each region to be reasonably similar. This has already been shown to be the case for all vessels in the Spencer Gulf-West Coast fleet. It would appear that this is true on a regional basis also. King (1978, 16 and 21) demonstrates that this is the case in Spencer Gulf whilst an examination of the catch effort patterns of the small numbers of vessels in other regions revealed that this was generally the case elsewhere as well. As a result, the simple sum of the hours trawled by all vessels over each month was used to measure the within year relative monthly effort levels in each region.

Assuming prawns are equally vulnerable to trawling in all months of the year[1] variations in monthly catch rates of a vessel or uniform mix of vessels will be proportional to changes in the abundance levels of the exploited stocks. Aggregate monthly catch rates, that is total catches divided by the total hours trawled by all vessels, can therefore be used to measure the within-year relative monthly abundance levels in each region.

The monthly effort and abundance indices for all regions on a yearly basis were derived by substituting the above measures of monthly effort and abundance into equation (B.V.1). The results are shown in Tables IV and V respectively.

Note that since calculation of the monthly abundance indices makes use of actual monthly catch rates, they could not be calculated for years in which fishing was not undertaken in one or more months. This precluded their calculation in the following instances:

West Coast: 1968, 1969, 1971, 1972, and 1973,

Gulf St, Vincent: 1968,

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[1]The validity of this assumption will be discussed below.

TABLE IV

MONTHLY ABUNDANCE INDICES BY REGION FOR YEARS
1968 TO 1977 (AVERAGE MONTHLY ABUNDANCE IN EACH YEAR = 100)

West Coast

	Jan.	Feb.	Mar.	April	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
1968	0	0	0	0	140	257	23	19	182	84	93	402
1969	25	14	0	0	0	0	18	175	195	201	322	251
1970	96	73	76	92	152	91	119	73	105	119	103	99
1971	54	94	19	4	0	75	255	153	115	108	242	81
1972	152	46	0	3	110	147	106	201	191	114	29	101
1973	0	20	27	12	173	163	220	136	83	120	109	137
1974	109	63	64	58	43	93	147	218	130	68	80	99
1975	114	22	30	38	112	248	189	156	65	70	94	63
1976	102	70	81	158	182	184	104	79	34	86	45	74
1977	121	96	99	72	13	133	240	131	82	72	121	55

Spencer Gulf

	Jan.	Feb.	Mar.	April	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
1968	22	33	45	16	65	156	124	95	139	180	179	147
1969	73	50	49	116	110	126	141	83	78	133	143	96
1970	87	121	134	149	145	107	121	45	52	86	110	44
1971	62	67	107	210	254	155	59	39	50	50	69	79
1972	107	127	107	168	167	109	33	31	31	64	172	83
1973	92	127	132	122	139	71	49	77	69	124	132	66
1974	81	113	121	118	157	112	38	48	62	112	151	87
1975	93	148	129	161	124	74	53	58	74	85	138	63
1976	101	143	176	136	118	79	68	61	63	80	95	79
1977	107	127	188	172	129	82	45	25	58	89	106	71

TABLE IV continued

Gulf St. Vincent

	Jan.	Feb.	Mar.	April	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
1968	0	0	0	0	23	149	194	74	181	317	262	0
1969	48	48	50	36	35	72	124	149	203	183	71	180
1970	95	120	116	125	173	68	26	20	58	116	154	130
1971	83	104	122	141	148	68	81	51	87	109	92	114
1972	88	126	105	101	149	139	16	44	101	96	139	96
1973	81	128	106	91	120	105	75	90	59	119	119	107
1974	66	80	142	142	166	116	48	51	61	115	121	92
1975	79	100	88	162	84	144	64	88	116	132	194	78
1976	82	100	151	117	124	96	95	67	61	109	123	77
1977	56	61	140	210	69	94	57	21	53	154	165	124

Investigator Strait

	Jan.	Feb.	Mar.	April	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
1975	0	0	0	0	0	0	0	0	253	208	444	296
1976	56	79	111	106	110	155	101	122	79	88	93	101
1977	114	65	110	140	68	179	68	126	104	92	91	42

TABLE V

MONTHLY EFFORT INDICES BY REGION FOR YEARS
1968 TO 1977 (AVERAGE MONTHLY EFFORT IN EACH YEAR = 100)

West Coast

	Jan.	Feb.	Mar.	April	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
1968	n.a.											
1969	n.a.											
1970	137	84	99	126	115	113	122	101	85	71	79	70
1971	n.a.											
1972	n.a.											
1973	n.a.											
1974	94	121	213	185	107	73	70	50	74	45	71	96
1975	138	102	70	100	143	128	103	85	74	80	97	81
1976	155	152	82	81	86	88	83	78	61	83	128	122
1977	149	139	350	43	82	48	41	63	68	72	97	47

Spencer Gulf

	Jan.	Feb.	Mar.	April	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
1968	67	61	130	178	172	96	73	74	99	69	108	73
1969	97	86	92	137	130	81	128	84	104	86	93	83
1970	95	89	188	188	124	125	60	52	56	65	76	84
1971	79	143	177	126	108	84	56	62	66	79	116	106
1972	105	147	152	142	97	86	92	80	57	74	97	71
1973	88	156	145	127	104	77	66	74	90	102	98	75
1974	64	138	201	178	105	62	58	80	83	71	92	67
1975	130	132	178	150	108	82	67	61	65	63	92	73
1976	100	124	159	128	107	83	66	77	67	87	111	93
1977	120	114	201	153	116	81	50	55	44	75	104	87

TABLE V continued

Gulf St. Vincent

	Jan.	Feb.	Mar.	April	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
1968	n.a.											
1969	131	110	100	102	113	121	79	66	107	115	71	85
1970	109	94	109	126	163	169	50	49	46	91	104	89
1971	115	103	100	107	102	101	87	81	81	117	99	109
1972	121	99	84	96	105	109	84	69	74	111	154	94
1973	73	77	81	109	92	103	76	75	92	140	167	114
1974	74	79	92	102	102	101	115	86	83	85	130	152
1975	83	100	96	127	115	117	55	66	67	71	145	159
1976	97	78	113	114	112	104	75	60	76	102	155	114
1977	85	115	119	114	120	126	69	82	81	84	108	97

Investigator Strait

	Jan.	Feb.	Mar.	April	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
1975	n.a.											
1976	90	89	107	143	146	134	114	63	55	55	81	123
1977	113	142	97	93	130	93	76	95	91	95	114	61

Investigator Strait: 1975.

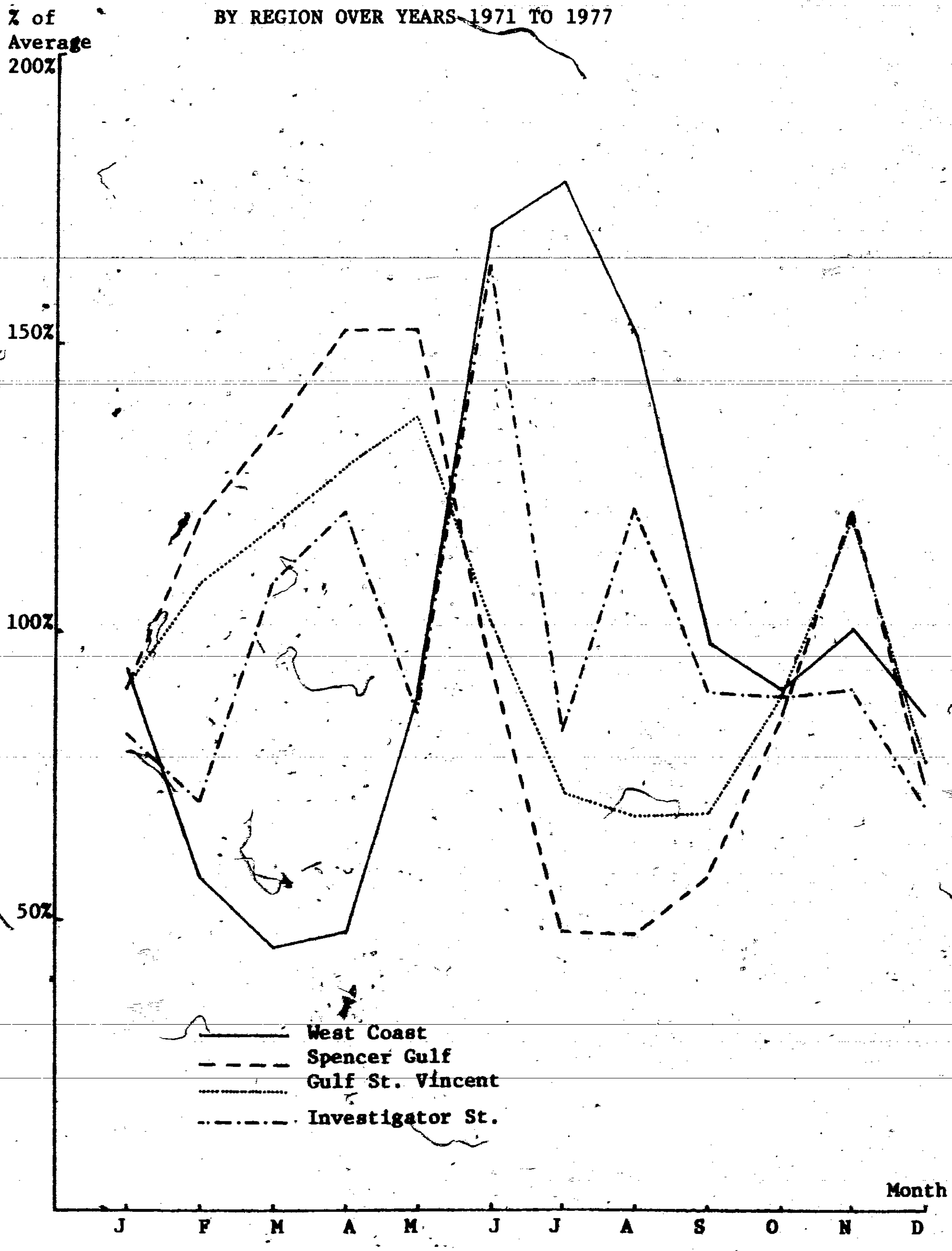
It can be seen that the effort pattern in Spencer Gulf changed considerably after 1970, with a more even distribution in the 1968 to 1970 period than in later years. This was probably partly due to the practice of some operators of switching to tuna fishing during the tuna season, which runs from January to May, during the early years of the prawn fishery. The dual fishery operations were disallowed after 1970, as outlined in Section B.II. For the West Coast, Gulf St. Vincent and Investigator Strait regions little trend was apparent. In addition, considerable random fluctuation for individual months was observed between years for all regions especially the West Coast. The greater variability for this last region was due to the small numbers of vessels normally operating there and the ability of vessels from the large Spencer Gulf fleet to switch to it when catch rates in the latter region were unsatisfactory.

The average monthly effort index levels over the years 1971 to 1977, when all operators have been full-time, are shown in Figure 5. It can be seen that in both Spencer Gulf and Gulf St. Vincent, fishing is heavier in the months immediately following the exit of juveniles from the nursery areas and towards the end of the year. The two peaks are somewhat more equal for Gulf St. Vincent than for Spencer Gulf, with the post-recruitment peak being more dominant in the latter case.

FIGURE 5

AVERAGE MONTHLY EFFORT INDEX LEVELS

BY REGION OVER YEARS 1971 TO 1977



On the West Coast and in Investigator Strait, however, effort is highest several months after the exit of prawns from the nursery areas. The very dominant West Coast peak is due to the ability of Spencer Gulf vessels to switch to it during the calmer winter months after the catch rate has declined in the major Spencer Gulf fishery.

Before discussing the abundance estimates, it should be noted that during the winter months from June to September water temperature declines and this has the effect of reducing the mobility of prawns and hence their vulnerability to capture.[1] This, rather than a decline in the prawn biomass, is considered to be the cause of the catch rate decline over this period.

From Table V it can be seen that the within-year abundance cycles in all regions have shown little trend, despite changes in effort patterns. The abundance levels for particular months do, however, vary considerably between regions, as shown by the average monthly levels over the 1971-77 period in Figure 6.

The greatest average within-year variation occurs in Spencer Gulf, where the peak March catch rate is over two and a half times the minimum rate. In the other regions the peak catch rate occurs later in the year and the cycle is considerably less pronounced.

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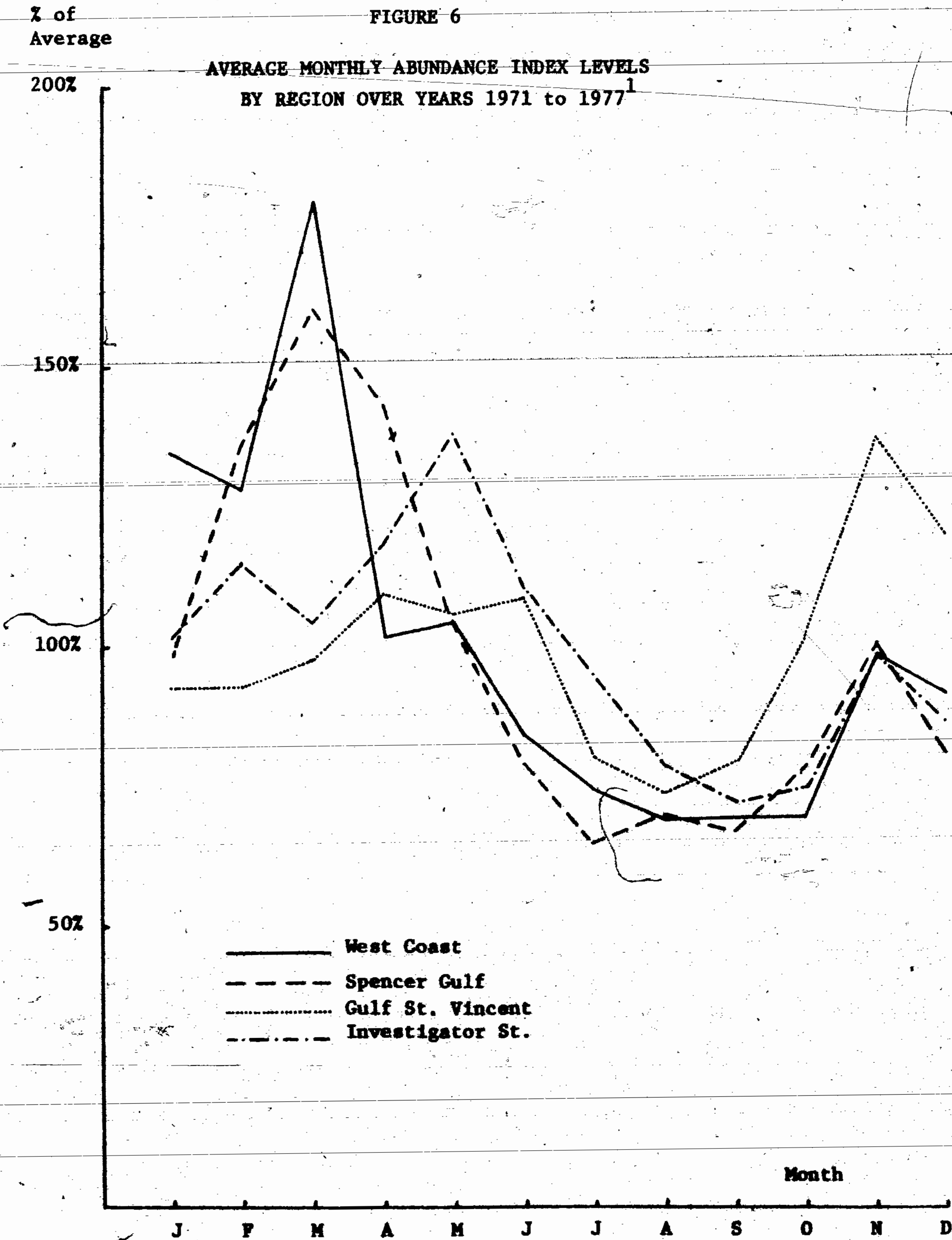
[1]The factors affecting the catchability of penaeid shrimps are analysed in detail in White (1975). See also King (1978).

FIGURE 6

AVERAGE MONTHLY ABUNDANCE INDEX LEVELS
BY REGION OVER YEARS 1971 to 1977[1]



1. For regions in which index was not available for all years, averages over available years were used.

The different catch rate cycles can probably best be explained in terms of the the stock segments being exploited in the different regions. The Spencer Gulf and West Coast operators concentrate on areas adjacent to the nursery areas, resulting in a major catch rate peak at the time of entry of new recruits to the fishery. Operators in Gulf St. Vincent, on the other hand, fish in areas occupied by the more mature, larger prawns. This leads to a peak catch rate later in the year. Both Olsen (1975, 237) and King (1978, 53-54) suggest that different age groups are exploited in the two major regions, Spencer Gulf and Gulf St. Vincent.

The explanation for the observed Investigator Strait abundance cycle is slightly more complex. The stocks exploited in this region come largely from nursery areas in Gulf St. Vincent. These do not reach the mouth of the gulf until some months after their exit from the nurseries. The fishing grounds in the strait are largely adjacent to the gulf, hence leading to a catch rate peak in about May at the time of arrival of the seasonal inflow.

The greater within-year variations in abundance in Spencer Gulf and the West Coast, despite effort being concentrated in the period of maximum abundance, may be due to heavier exploitation of the stocks in these regions. Heavier fishing leads to a smaller residual stock at the time of entrance of new recruits, and hence a larger catch rate jump when this inflow occurs.

The weight and size composition of the catch taken in a region over a year with a given level of fishing will therefore depend on the seasonal distribution of fishing effort and the segments of the stock which are being exploited.

VI. THE IMPORTANCE OF THE FISHERY

In 1976-77 the prawn fishery became the most valuable in South Australia in terms of value of aggregate production, due mainly to dramatic increases in prawn prices. Catch has been reasonably stable in recent years. Yearly catch and revenue levels are given in Table VI.

It is somewhat misleading to consider the fishery as a single entity, given that vessels are not permitted to move from one region to another, and that the fishing operation has different characteristics in each region. Yearly catch levels for each fleet are given in Table VII. It can be seen that by far the largest catch is taken by the West Coast-Spencer Gulf fleet, followed by the Gulf St. Vincent fleet and lastly by the Investigator Strait fleet. Catches have declined somewhat in recent years in Spencer Gulf but have increased steadily in Gulf St Vincent.

Unfortunately there is little information available on the prawn prices received by operators in each region. As a result, exact calculation of the value of the production of each region on a yearly basis was not possible. The overall yearly prices and regional catches can, however, be combined with estimates of the normal price differentials between regions to give rough approximations of the above prices. Based on limited evidence it

TABLE VI

CATCH, REVENUE AND PRICES FOR THE SOUTH AUSTRALIAN PRAWN FISHERY FOR YEARS 1969-70 TO 1976-77

	Catch (tonnes)	Revenue ($'000)	Price/Kg. ($)
1969-70	1302	1637	1.26
1970-71	1213	1551	1.28
1971-72	1524	2285	1.50
1972-73	1789	2997	1.68
1973-74	2921	3797	1.30
1974-75	2530	3795	1.50
1975-76	2679	7761	2.90
1976-77	2644	9000	3.40

Source: Australian Bureau of Statistics (1977).

TABLE VII

ESTIMATED TOTAL VALUE OF CATCH AND VALUE OF AVERAGE CATCH PER OPERATOR BY FLEET FOR YEARS 1969-70 TO 1976-77.

West Coast - Spencer Gulf

Year	Catch (tonnes)	Price/Kg. ($)	Value ($ 000)	No. of Operators	Revenue/Operator ($ 000)
1969-70	1158.2	1.22	1413.0	28	50.5
1970-71	1059.8	1.23	1303.6	30	45.1
1971-72	1276.7	1.42	1812.9	35	51.8
1972-73	1486.4	1.59	2363.4	36	65.6
1973-74	2548.6	1.24	3160.3	36	87.8
1974-75	2230.6	1.42	3167.4	40	79.2
1975-76	2058.3	2.76	5680.9	40	142.0
1976-77	2087.0	3.22	6720.1	42	160.0
1977-78	1662.0	2.87	4770.0	42	113.6

St. Vincent Gulf

Year	Catch (tonnes)	Price/Kg. ($)	Value ($ 000)	No. of Operators	Revenue/Operator ($ 000)
1969-70	101.2	1.71	173.1	4	43.3
1970-71	127.1	1.72	218.6	8	27.3
1971-72	210.8	1.99	419.5	10	42.0
1972-73	229.4	2.23	511.6	10	51.2
1973-74	354.2	1.74	616.3	10	61.6
1974-75	342.2	1.99	681.0	12	56.7
1975-76	450.8	3.86	1940.1	12	145.0
1976-77	502.4	4.35	2185.4	14	156.1
1977-78	378.4	4.02	1521.2	14	108.7

TABLE VII continued

Investigator Strait

Year	Catch (tonnes)	Price/Kg. ($)	Value ($'000)	No. of Operators	Revenue/Operator ($ 000)
1975-76	146.5	3.31	484.9	5	97.0
1976-77	143.0	8.86	552.0	5	110.4
1977-78	185.2	3.44	637.1	5	127.4

Source: Australian Bureau of Statistics (1977) and information supplied by the Department of Agriculture and Fisheries, South Australian Government.

is considered that prices in Gulf St. Vincent have on average been approximately 40% higher than those in Spencer Gulf and the West Coast.[1] Prices in Investigator Strait appear to be approximately mid-way between the two, hence a 20% markup[2] above Spencer Gulf was assumed for this region. The yearly prices for each region were then estimated as follows :

$$Ps = (P\ Y) / (Ys + 1.2\ Yi + 1.4\ Yv) \quad \text{(B.VI.1)}$$

$$Pi = 1.2\ Ps \quad \text{(B.VI.2)}$$

$$Pv = 1.4\ Ps \quad \text{(B.VI.3)}$$

where:

P = Average overall price per kilogram for year

Y = total overall catch, in kilograms for year

Pv, Pi, Pv = average price per kilcgram for year in Spencer Gulf and the Wevt Coast, Investigator Strait and Gulf St. Vincent

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[1]Data collected by the Department of Agriculture and Fisheries from a few processors indicated that the price differential of Gulf St. Vincent operators had been 47%, 34% and 44% in 1973-74, 1976-77 and 1977-78 respectively.

[2]Given that the bulk cf the prawns caught in Investigator Strait have already passed through Gulf St. Vincent, it would appear that prices in the former should be at least as high as in the latter and so the 20% markup is toc low. There are, however, three main reasons why this is not the case:
1. A significant component of the Investigator Strait catch originates in nursery areas off the north-east coast of Kangaroo Island. Prawns from these areas are caught socn after recruitment and are hence fairly small.
2. Effort in Gulf St. Vincent is concentrated more towards the end of the year when prawns are especially large.
3. Gulf St. Vincent operators have better access to the major local market in Adelaide and therefore face a slightly higher price scale.

Ys, Yi, Yv = total catch, in kilograms for year in Spencer Gulf and the West Coast, Investigator Strait and Gulf St. Vincent. The estimated regional prices and resultant regional revenues are given in Table VII.

By dividing the value of the catch for each fleet by the number of vessels in it, average revenue per licence can be obtained. These averages are also given in Table VII.

As estimates of costs of operators are not directly available, no comments can be made regarding actual profit levels without further analysis. However, it is clear that profitability has increased markedly in the last three years because of the escalation of world prawn prices.

C. THEORETICAL ASPECTS OF THE ESTIMATION OF ECONOMIC SURPLUS OF A FISHERY

I. THE CONCEPT OF ECONOMIC SURPLUS

The economic surplus derived from a fishery in a period equals the value of production less the opportunity cost of the resources used up in producing it. It is a function of the size of the catch, the effective demand for each unit of catch, the level of effort required to take it and the opportunity cost of each unit of effort. In general terms

$$Rt = \sum_{i=1}^{Yt} Dit - \sum_{j=1}^{Xt} Ojt \qquad \text{(C.I.1)}$$

where:

Rt = economic surplus from the fishery in period t

Dit = the price buyers are willing to pay for the ith unit of catch in t

Ojt = the opportunity cost of the resources used to produce the jth unit of fishing effort in t,

Yt = total catch level in t,

Xt = total effort level in t.

The surplus can be broken down into three components to reflect how it is distributed, namely

consumer surplus = $\sum_{i=1}^{Yt} (Dit - Pit)$,

resource rent = $\sum_{i=1}^{Yt} Pit - \sum_{j=1}^{Xt} Ojt$,

and producer surplus = $\sum_{j=1}^{Xt} (Cjt - Ojt)$

where:

Pit = the price actually paid for the ith unit of catch in t,

Cjt = the actual outlays required or receipts foregone to produce the jth unit of effort in t.[1]

In practice, because Dit and Cjt are not directly observable and must therefore be estimated using proxy prices, it is often assumed that consumer and producer surpluses are equal to zero, that is that

Dit = Pit

and

Cjt = Ojt.

This means that (C.I.1) reduces to

$$Rt = \sum_{i=1}^{Yt} Pit - \sum_{j=1}^{Xt} Cjt \qquad \text{(C.I.2)}$$

or

$$Rt = Yt\ Pt - Xt\ Ct \qquad \text{(C.I.3)}$$

where:

$$Pt = \sum_{i=1}^{Yt} Pit / Yt$$

$$Ct = \sum_{j=1}^{Xt} Cjt / Xt.$$

The present value of the perpetual stream of economic surpluses equals the the sum of their values after they have been discounted by the social rate of time preference. That is

$$R = \sum_{t=0}^{\infty} Rt\ (1+r)*(-t) \qquad \text{(C.I.4)[2]}$$

or

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[1]The components are those identified in Copes (1972).

[2]'*' signifies 'to the power of'.

$$R = \sum_{t=0}^{\infty} \left(\sum_{i=1}^{Y_t} Dit - \sum_{j=1}^{X_t} Ojt \right) (1 + r)*(-t) \qquad \text{(C.I.4)}$$

where:

r = the social rate of time preference between periods.

From an economic viewpoint, the resource is being exploited most efficiently when the present value of this perpetual stream of surpluses is maximised.

The only independent variable is the level of fishing effort. It follows that the economic surplus from a single period will be maximised when the value of the catch obtained from a further effort increase, however produced, is less than the cost of the inputs used to produce it, that is when

$$dRt / dXt = (dYt / dXt)\ Dit - Ojt = 0$$

where:

i = the marginal unit of catch in period t

j = the marginal unit of effort in period t.

The present value of the perpetual stream of economic surpluses is maximised when the discounted value of the rent increment in any period from a further effort increase in that period is equal to the present value of the cost of producing it. This cost is made up of both the value of the inputs needed to produce the effort increase and the reduction it causes in the economic surpluses in later periods via the reductions in catch levels at the given levels of effort.[1] In mathematical terms, R is maximised when

$$dR / dXk = <(dYk / dXk)\ Dik - Cjk> (1 + r)*(-t) - \sum_{t=k+1}^{\infty} (dYt / dXk)\ (1 + r)*(-t) = 0$$

where:

$k = 0, 1 \ldots$

A considerable literature has been built up in recent years exploring the implications for the optimising distribution of effort over time of various rates of time preference and degrees of between-period yield-effort interdependence.[2] In general, the higher the rate of time preference and the greater the degree of between period inter-dependence the higher the optimum effort levels in more immediate periods and the lower the optimum effort levels in periods further into the future.

Maximisation of the economic surplus in each period will lead to maximisation of the present value of the perpetual stream of economic surpluses only if society is indifferent as to the period in which the surplus is received, that is $r = 0$, or if the catch in each period is completely independent of the effort levels in all previous periods, that is $dYt / dXk = 0$ for all $t > k$.

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[1]The reasons for these catch reductions are related to the nature of the production functions for renewable resources such as fish stocks. This aspect will be developed further later in the study.

[2]See for example Clark and Munro (1975).

The biology of Western King prawns is such that in fact this latter requirement is considered to be largely fulfilled.[1] As a result, provided the econcmic surplus from the exploitation of each stock in each period is maximised so is the present value of the perpetual stream of such surpluses.

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[1] See Section B.III.

II. THE YIELD FUNCTION

The above discussion highlights the importance of the yield-effort relationship in determining the size of the economic surplus from a fishery. Because the analysis is concerned with exploitation of living organisms, this relationship is essentially biologically based. As a result, yield functions for each fish stock, defined as those members of a given species which inhabit the same area and interact biologically, are normally considered separately.

Formulation of the yield function for a given fish stock is a task of considerable complexity, and population dynamicists have been exploring the field for a considerable period of time. In order to simplify the analysis, attention is normally focused on sustainable yields, that is those yield-effort combinations which are in steady-state equilibrium.

The usable stock of a renewable resource such as a fishery is in a continuous state of adjustment. It is increased by growth and recruitment and depleted by natural mortality and fishing. This can be represented graphically as shown in Figure 7 or algebraically by the equation

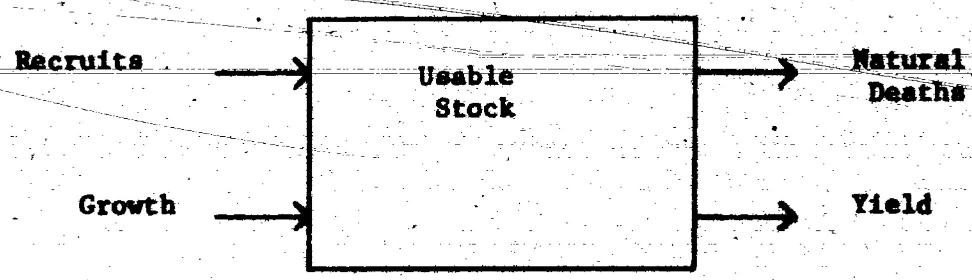
$$St+1 = St + Rt + Gt - Mt - Yt \qquad (C.II.1)$$

where:

St = the average size of the stock at the beginning of period t

FIGURE 7

DYNAMICS OF AN EXPLOITED FISH STOCK



Source: Ricker (1975, 25)

R_t = the level of recruitment to the stock during period t

G_t = the level of growth of existing members of the stock during period t

M_t = the level of natural mortality of existing members of the stock during period t.

In a steady state situation,

$S_t = S_{t+1}$, for t = 0, 1, ...

and therefore

$$Y_t = R_t + G_t - M_t, \text{ for } t = 0, 1, \ldots \quad \text{(C.II.2)}$$

The sum $(R_t + G_t - M_t)$ is normally referred to as the sustainable natural surplus.

But yield in each period is itself a function of the effort level and the size of the usable stock to which it is applied. That is

$$Y = S\,f(X) \quad \text{(C.II.3)}$$

where:

f(X) = the proportion of S captured with X units of effort. Note that effort is normally measured in units of fishing mortality, that is each unit of effort removes an equal proportion of the total fish stock.[1]

In addition the levels of recruitment, growth and natural mortality are also affected by the size of the usable stock. That is

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[1]The question of how this is estimated in practice is discussed in detail in a later section.

R = R(S) (C.II.4)

G = G(S) (C.II.5)

M = M(S) (C.II.6)

Equations (C.II.2) to (C.II.6) constitute a system in dynamic equilibrium.

For a fishery with no seasonal recruitment, growth or natural mortality patterns, the choice of the time period is largely arbitrary. However, most fish stocks are subject to a regular annual abundance cycle, hence yearly periods are normally used.

Two different approaches have been taken in attempts to measure the various possible equilibrium positions for individual fisheries:

1. The dynamic pool model of Ricker (1975) and Beverton and Holt (1957),
2. The surplus yield model of Schaefer (1954) and more recently, Fox (1970).[1]

The details of the dynamic pool model are extremely complex, but in simple terms it entails estimation of the individual functions relating R, G and M to S and Y to X for each level of S.[2] Computer simulation then allows calculation of

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[1]The two approaches are compared in Schaefer and Beverton (1963).

[2]Gulland (1969) outlines the procedures which can be used whilst Ricker (1975) and Beverton and Holt (1957) give very detailed expositions.

the equilibrium stock and hence catch levels for each effort level.

A key determinant of the yield-effort function appears to be the relationship between stock size and recruitment.[1] In general, recruitment may be:

1. Positively related to stock density,
2. Unaffected by stock density,
3. Negatively related to stock density.[2]

These give rise to yield curves which are domed, asymptotic and increasing without limit respectively, as illustrated in Figure 8.[3] The eventual yield curve shape will of course also be affected by the relationships betwen density and growth and natural mortality.

The dynamic pool model incorporates separately each of many factors affecting the natural surplus, which helps to refine the estimation of yield-effort positions of the fish stock. However, it requires extremely detailed information concerning the biological characteristics of the stock, and this prevented its use in the present study.

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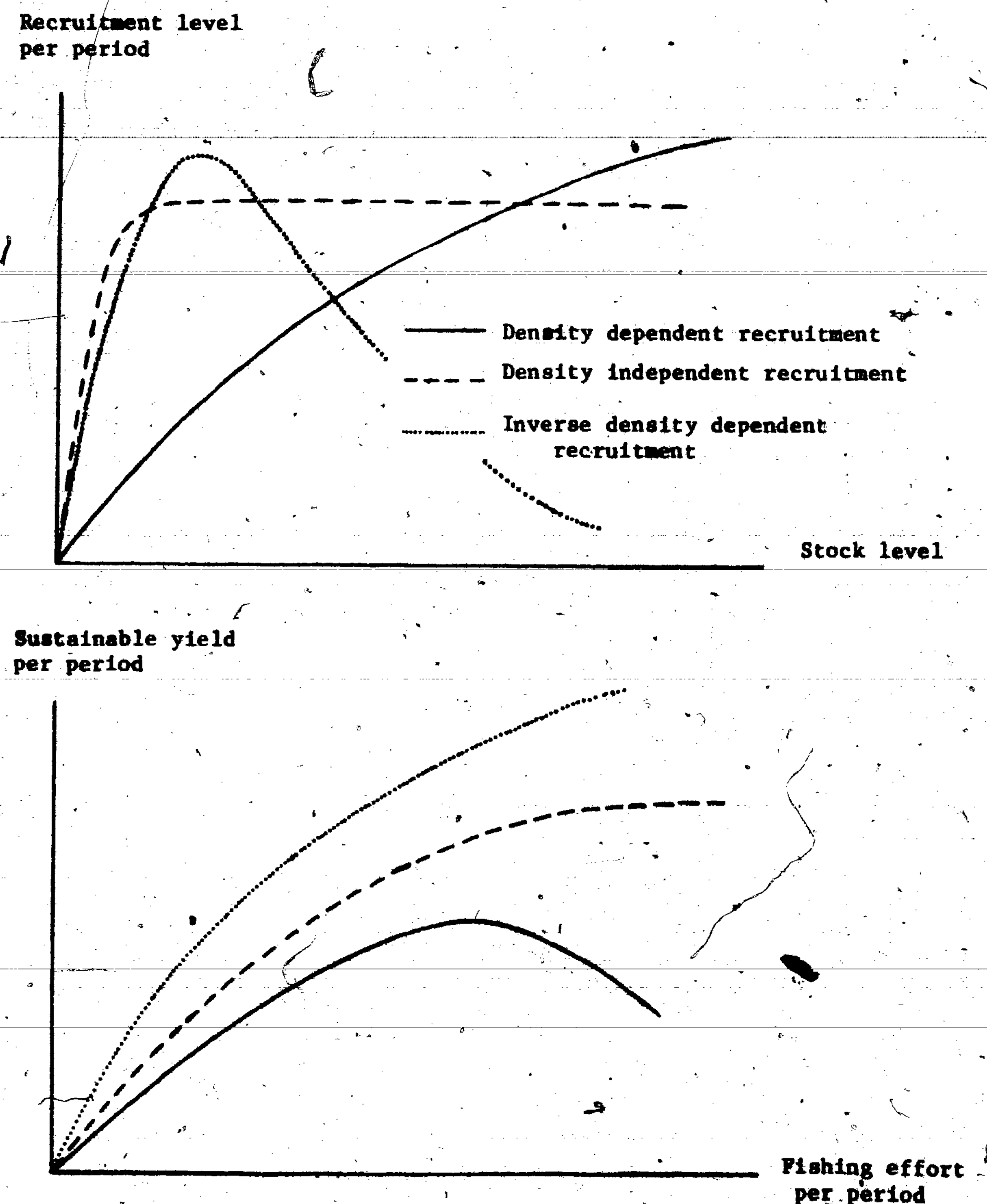
[1]See Gulland (1974, 92-94).

[2]Obviously relationships 2. and 3. cannot hold at all stock levels. However, they may apply over those levels which are realistic in terms of the fishery being sufficiently profitable to be continued.

[3]Ricker (1975, 280-296) gives a very detailed exposition of the mathematical forms of the various alternatives.

FIGURE 8

RELATIONSHIP BETWEEN STOCK LEVEL, RECRUITMENT AND SUSTAINABLE YIELD



The surplus yield model makes the strong simplifying assumption that the relationship between (R + G - M) and S can be represented by a simple function. That is:

$$F(S) = R(S) + G(S) - M(S). \qquad \text{(C.II.7)}$$

But in equilibrium

$$F(S) = Y = S\ f(X). \qquad \text{(C.II.8)}$$

Since S is not directly observable, it is normally replaced by the catch rate, to which it is by definition proportional. Equation (C.II.8) therefore becomes

$$Y = (Y/X)\ f(X) \qquad \text{(C.II.9)}$$

or simply

$$Y = f(X). \qquad \text{(C.II.10)}$$

Equation (C.II.10) is then estimated from observed values of Y and X using suitable statistical techniques.[1]

Whilst the advantage of the technique is the minimal data requirement, it has two major weaknesses:

1. The observed yield-effort levels may not represent sustainable positions.
2. The correct form of f(X) is unknown.

If the level of fishing effort varies from period to period, unless the natural surplus in one period is independent of the yields of previous periods, observed yield-effort combinations will not be sustainable. In such cases it is

[1]The normal method is to apply ordinary least squares regression to adjusted yield-effort data. See Fox (1975).

necessary to deduce the sustainable catch levels indirectly, a somewhat hazardous task.[1] Fortunately, as discussed in Section B.III, there is little between-year yield-effort interdependance in the fishery under consideration, hence this is not likely to be a source of difficulty in this study.

The form of f(X) should ideally be simple but provide a good approximation to the true yield function. The problem is that there are no objective criteria for deciding what the best form is, apart from statistical explanatory power.

Most research to date has been undertaken on stocks where catch initially increased, then declined as effort increased, suggesting a bell or dome shaped yield curve. The two most common forms of yield equation have therefore been a parabola[2] and an exponential[3], that is -

Y = a X - b X*2 (C.II.11)

and

Y = X e*(a - b X) (C.II.12)

where:

----

[1]A large number of lagging, averaging and subjective adjustment methods have been advocated, none of which are entirely satisfactory. See for example Copes (1978, 36-38), Gulland (1969, 120-121 and 1974, 73-74), Ricker (1975, 280-296) and Schaefer (1954, 32-33).

[2]This form was initially developed by Graham (1939) but is usually associated with Schaefer (1954) who applied it to the Pacific halibut fishery.

[3]See Fox (1971).

a,b = constants.

The uncertainty as to the correct form of the yield function can, however, be exaggerated. Even where insufficient data are available to apply the complete dynamic pool model, some knowledge of the biology of the stock may be available, and this will often give a general idea of the type of yield curve to be expected. This is the case for the prawn stocks under consideration.

It was concluded in Section B.III that for Western King Prawns, the level of recruitment was independent of the size of the parent stock. It is therefore considered that the yield curve for stocks of this species is of the general shape given by the broken line curve in Figure 8. This curve had three general properties:

1. It had a positive but continuously declining slope,
2. It approached a positive asymptote,
3. It passed through the origin.

A simple production function with all of these properties is:

$$Y = a\,(1 - b^{X}) \qquad \text{(C.II.13)}$$

where:

a, b = constants

$0 < b < 1$.

The larger is b the more rapidly the yield approaches the asymptote a. This form of yield equation has already been applied successfully to the Gulf of Mexico shrimp fishery.[1]

Another possible form which meets only two of the suggested requirements is

$$Y = a X^{*}b \qquad (C.II.14)$$

where:

a, b = constants

$0 < b < 1$

Only (C.II.14) can be expressed in linear form, namely

$$\log Y = a + b \log X \qquad (C.II.15)$$

thus allowing for direct estimation of the parameters. However, (C.II.13) can be estimated by itineration by estimating b for different values of a and b and chcosing those values which maximise the explanatory power of the equation. It is convenient to express (C.II.13) in log form namely

$$\log (1 - Y/a) = B X \qquad (C.II.16)$$

where:

B = log (b). before estimating the parameter values.

Estimation of both forms will therefore be attempted for each of the South Australian prawn stocks.

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[1]See Griffin et al. (1976).

D. THE ESTIMATION OF FISHING EFFORT

I. A MODEL OF VESSEL FISHING POWER

As outlined in Section C.II, when calculating the yield function, effort is normally measured in units of fishing mortality that is, each unit of fishing effort reduces the stock level by an equal percentage. The effort data available from a fishery, however, is typically available in terms of periods and areas of operation of individual fishing units. It is therefore necessary to express the latter data in terms of units of fishing mortality before estimation of the yield curve and hence economic surpluses can be undertaken.

As outlined by Anderson (1977b, 22 and 155), the share of the available yearly stock taken by a fishing unit per unit of operating time will depend cn:

1. The relative density of those subsections of the stock which the unit exploits,
2. The shares of these subsections which are captured.

It is generally considered that during a year prawn abundance varies with time, depth and location.[1] The relative capture rates of different units when exploiting stocks of equal abundance, normally referred to as their relative fishing powers,[2] are a function of the characteristics of the fishing units.

The usual procedure is to adopt as the unit of effort the rate of fishing mortality induced by the operation of a particular standard fishing unit per unit of time, when operating on a given stock segment.[3]

To simplify the analysis, assume that identical subsections of the stock are exploited by all units. In this case the effort level of a given unit over a year equals the product of its fishing power relative to the standard unit and the amount of time it spends fishing. Aggregate effort equals the sum of the effort levels of the individual units. That is

$$Xt = \sum_{i=1}^{N_t} FPi\ Tit \qquad (D.I.1)$$

where:

Xt = the effort in period t in standard fishing unit time units

FPi = the fishing power of unit i relative to the standard unit

Tit = the period of operation of unit i in period t

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[1]See for example King (1978) and White (1975).

[2]See Beverton and Holt (1957, 172-73).

[3]See for example Beverton and Holt (1957, 29-30 and 149-51)

Nt = the number of units operating in period t.

Provided comparative catch rates for the standard unit and all other units are available, the fishing powers of the former in terms of the latter can be calculated as follows:

$$FPi = (Y/T)i \ / \ (Y/T)s \qquad \text{(D.I.2)}$$

where:

$(Y/T)i$ = the catch rate of unit i per unit of time

$(Y/T)s$ = the catch rate of the standard unit per unit of time.

It is frequently simpler, however, to use the relative catch rates of a sample of the fishing units to first calculate a relationship between catch rate and various fishing unit characteristics and then use the values of these characteristics for all units to estimate their relative fishing powers. In algebraic terms

$$(Y/T)i = f(C1i, C2i, \ldots) \ / \ f(C1s, C2s, \ldots) \qquad \text{(D.I.3)}$$

and therefore

$$FPi = f(C1i, C2i, \ldots) \qquad \text{(D.I.4)}$$

where

C1i, C2i, ... = the values of characteristics C1,C2, ... for unit i

C1s, C2s, ... = the values of characteristics C1,C2, ... for the standard unit.

The latter indirect procedure eliminates the need for the standard unit to in fact be one of the actual units. It also allows estimation of the fishing powers of potential new entrants, which may be very useful for management purposes. It was therefore the procedure adopted in the present study.

Equation (D.I.3) can be generalised to cover the case of multiple abundance levels by the inclusion of the abundance level as an additional variable. It therefore becomes

$$(Y/T)i = f(Ai, C1i, C2i, \ldots) \qquad (D.I.5)$$

where:

Ai = the abundance of the stock being fished by unit i.

Two types of relationships have been suggested for f(Ai, C1i, C2i, ...). The most common form[1] has been a logarithmic function,

$$(Y/T)i = \prod_{j=1}^{n} Ai\ (Cji^{*}Bj)$$

or

$$\log (Y/T)i = \log Ai + \sum_{j=1}^{n} Bj \log (Cji) \qquad (D.I.6)$$

where:

n = the number of fishing unit characteristics

B1, B2, ... = constants.

This form implies a proportional relationship between fishing power and the values of unit characteristics since

$$d(Y/T)i \;/\; dCji = (Bj/Cji) \prod_{j=1}^{n} Ai\ (Cji^{*}Bj)$$

and therefore

$$\langle d(Y/T)i \;/\; (Y/T)i\rangle \;/\; (dCji/Cji) = Bj.$$

This property seems intuitively sensible, since one would expect

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[1]See for example Beverton and Holt (1957, 172-76), Griffin et al. (1977), Gulland (1956) and Robson (1966).

the catch rate increase from a given absolute change in the level of a single characteristic to depend on the existing level of all characteristics, including the adjusted one.

A linear relationship,

$$(Y/T)i = Ai + \sum_{j=1}^{n} Bj\ Cji \qquad (D.I.7)$$

has also been used in several studies.[1] Here

$$d(Y/T)i \ / \ dCji = Bj$$

and is therefore independent of the current unit characteristics and the abundance level.

Since both equations (D.I.6) and (D.I.7) are linear they can be estimated using multiple regression techniques, a dummy variable being introduced for each abundance level.

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[1]See for example Beverton and Holt (1957, 172-76), Griffin et al. (1977) and Sluczanowski (1978).

II. FISHING UNIT AND ABUNDANCE VARIABLES

The catch rate per unit of time normally used in analysis of the South Australian prawn fishery is kilograms taken per hour spent actually trawling. This is an excellent measure of catch per unit of productive time and was therefore adopted for use in the regression.

When choosing the fishing unit characteristics for inclusion in the model, there are obvious practical difficulties, since some, such as skipper and crew skill are extremely difficult to quantify whilst many others, although quantifiable, are not readily available. It follows that the variables used are often far from ideal.

The major previous study of fishing power in shrimp fisheries, undertaken in the Gulf of Mexico fishery[1] found that the significant characteristics were BHP of units and the length of the footrope, a measure of net size. Characteristics which were found to be insignificant were gross tonnage, length and age of unit. Because of data limitations, the above study was forced to make the strong assumption that individual units were not modified in any way over the survey period of 10 years.

In the present study, values of only a limited number of unit characteristics were available, namely unit length, BHP and

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[1]See Griffin et al. (1977).

type of rig (single or double). They were, however, available on a yearly basis, hence allowance could be made for modifications carried out to specific units over the 1968-76 period being considered.

Ideally, one would like to segment observations in such a way that all units operating in each group are exploiting stocks of exactly equal abundance and so standardise completely for abundance differences. This is obviously impossible in practice. The results will, however, be unbiased provided there is no relationship between unit characteristics and abundance within the strata actually adopted.

As discussed above, prawn abundance varies with time, area and depth of trawling. For the South Austrlian fishery, however, catch rate data for each fishing unit were readily available only by calendar year and region (West Coast, Spencer Gulf, Gulf St. Vincent and Investigator Strait). In view of the uniformity of the seasonal effort patterns for units within each year and region,[1] it was considered little distortion would be introduced by the use of annual catch rates, despite the marked within-year abundance cycles. The use of annual rates also facilitates the elimination of random elements in monthly catch rates.

It was also considered that because of the well established nature of the West Coast, Spencer Gulf and Gulf St. Vincent

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[1] See Section B.V.

grounds virtually all of the operators had a good knowledge of the areas of maximum abundance. It follows that differences between the abundances of the stock segments exploited by individual operators in a region at a certain point in time were probably largely due to chance factors.

It was therefore concluded that there was unlikely to be a significant relationship between any unit characteristics and abundance of exploited stock segments for units within each region-year strata for the three established regions.

However, the Investigator Strait grounds are still in the development stage, having only been opened up in 1975. It is therefore possible that some operators in this region may possess superior knowledge and hence consistently exploit areas of superior abundance. To avoid the bias this latter effect could introduce, only observations from the three other regions were included in the regression.

Lastly, a few units fished for only very short periods in particular region-time strata, and, presumably because of their unfamiliarity with the grounds, recorded much lower than average catch rates. To take this into account, a "learn" dummy variable was introduced to segregate catch rates of those units operating less than 100 hours in a given region-time strata from the rest of the observations.

The data set therefore consisted of catch per hour on a region-year basis for almost all vessels operating in each of the three established regions between 1968 and 1976, and the length, BHP, rig and hours trawled of each vessel. There were 504 observations altogether, with the number of observations within each region-year strata varying from under ten to over forty.

III. STANDARDIZATION OF EFFORT FOR FISHING POWER CHANGES

All of the variables included in the model were found to be significant at the 95% level for equation (D.I.6), but for equation (D.I.7) the BHP coefficient was insignificant. The coefficient values and t statistics for each of the characteristics and the correlation coefficients for the total equations are shown in Table VIII.

In view of the intuitive appeal of the log linear model, it was used to estimate relative fishing powers, there being little difference between the equations in terms of explanatory power. It implies that 1% increases in vessel length and BHP lead to .54% and .18% increases in fishing power respectively, that switching from single to double rig will increase fishing power by 30% and that units trawling for less than 100 hours in a particular region-time strata have a 30% lower fishing power than other units.

The results for vessel length and BHP are not particularly surprising, since vessel length is closely linked to the length of footrope and hence the width of ocean floor the net or nets sweep whilst BHP affects the speed with which it can be towed.

TABLE VIII

ESTIMATED COEFFICIENTS OF FISHING UNIT CHARACTERISTICS AND COEFFICIENTS OF DETERMINATION USING LOG LINEAR AND LINEAR MODELS OF VESSEL FISHING POWER

Model	Characteristic				R^2
	Length or log (length).	BHP or log (BHP).	Double rig	Learn	
Log linear, (D.I.6)	.544 (5.212)	.178 (3.737)	.272 (6.468)	-.350 (6.353)	.658
Linear, (D.I.7)	1.641 (7.570)	.010 (1.147)	12.406 (7.809)	-8.879 (4.221)	.656

The substantial improvement caused by the adoption of double rig is somewhat larger than expected. The supposed advantages[1] of this type of gear are that it increases the feasible footrope length, improves trawling stability and ease of handling of the catch and adds to the versatility of the gear. It may, however, lead to instability, especially for small vessels, if one of the nets is snagged during trawling.

To test the stability of the estimated coefficients, the log linear equation was rerun on a regional and on a yearly basis. The 95% confidence intervals for each of the coefficients in these segmented groupings were then compared with those estimated using all the data simultaneously. The results are illustrated in Figures 9, 10, 11, and 12.[2]

Ideally, the intervals for the subgroups should encompass those derived using all observations. Whilst this was largely true for the double rig coefficient it was not the case for the coefficients of the length, BHP or learn variables. The instability in the learn coefficient was probably due to the small numbers of observations within each strata. For length and BHP it was considered to be due to the high degree of correlation between the two variables resulting in substantial multicollinearity. The variations were therefore largely

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[1]See Sluczanowski (1978, 18-20).

[2]This test was suggested in Griffin et al. (1977, 20-28)

FIGURE 9

95% CONFIDENCE INTERVALS FOR LOG(LENGTH) COEFFICIENT USING OVERALL, REGIONAL AND YEARLY DATA

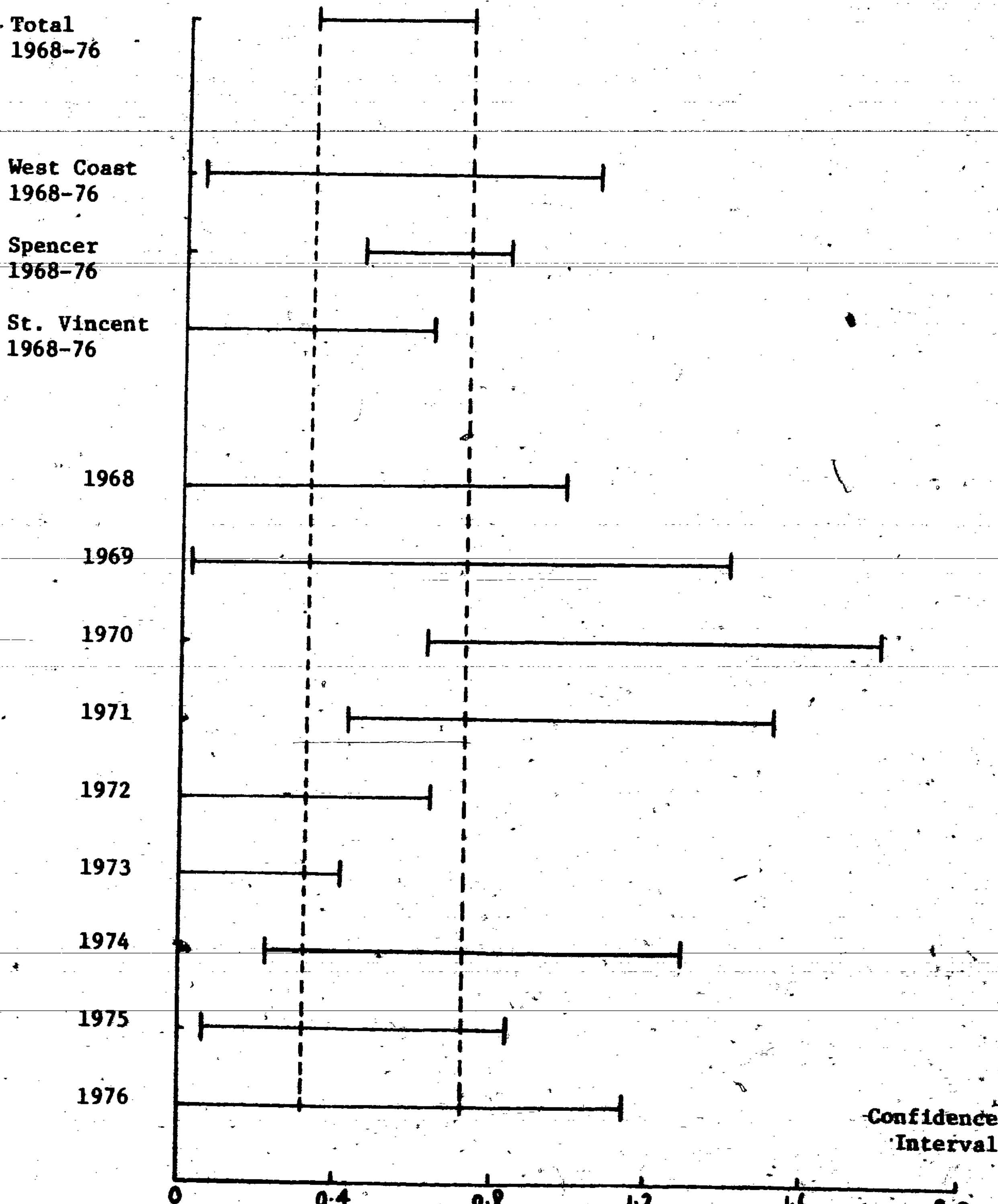


FIGURE.10

95% CONFIDENCE INTERVALS FOR LOG(BHP) COEFFICIENTS
USING OVERALL, REGIONAL AND YEARLY DATA

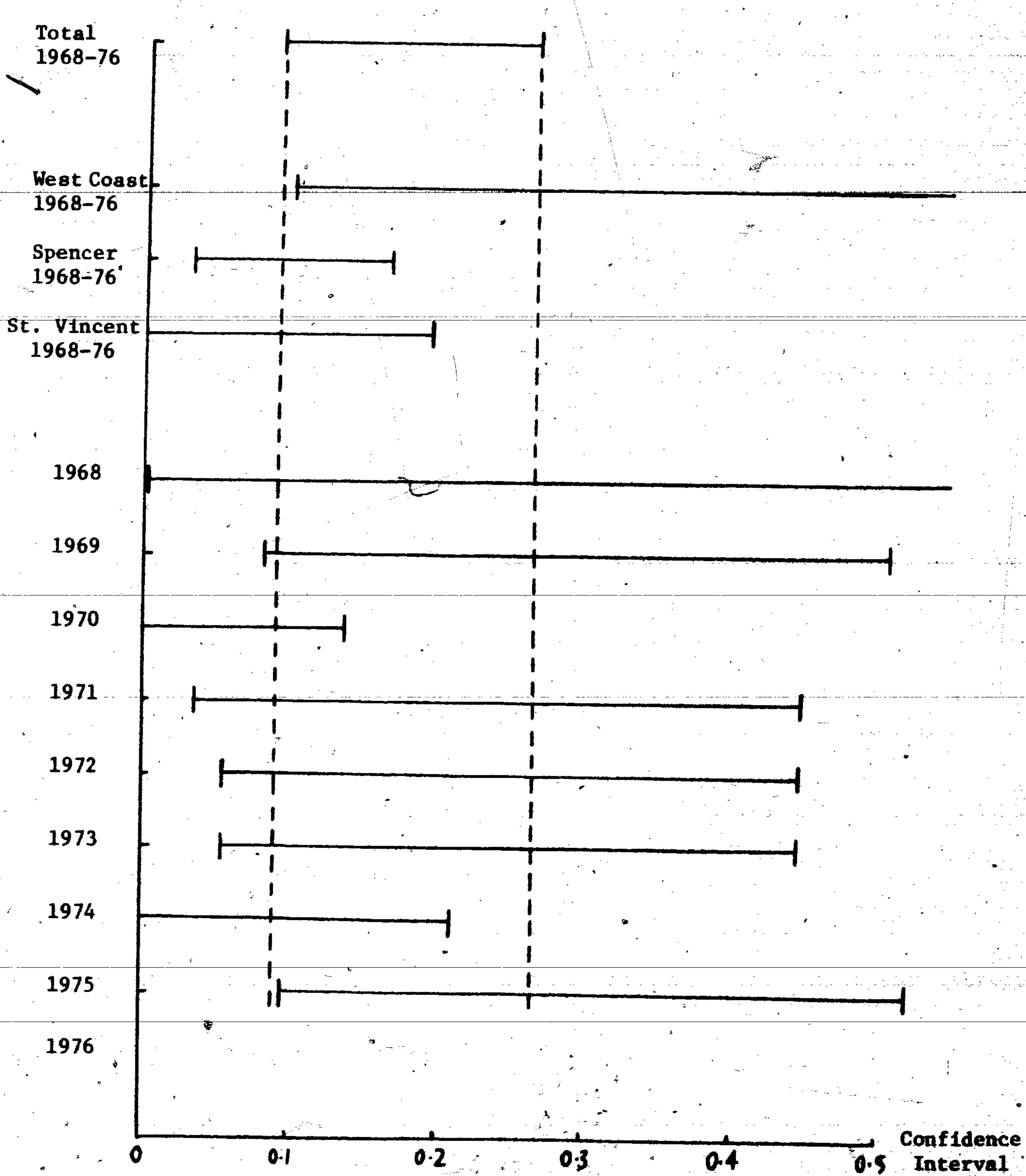


FIGURE 11

95% CONFIDENCE INTERVALS FOR DOUBLE RIG COEFFICIENT
USING TOTAL, REGIONAL AND YEARLY DATA

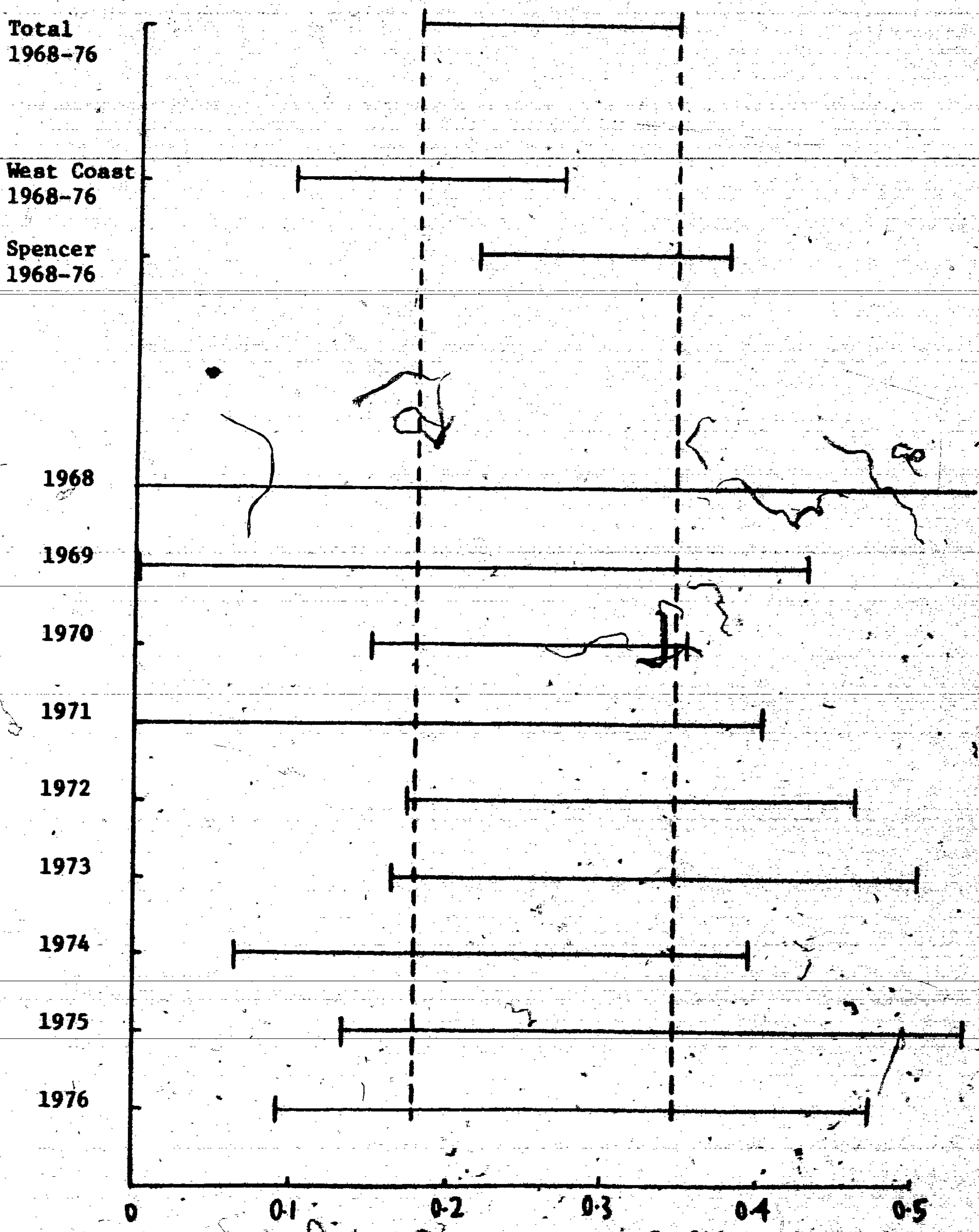
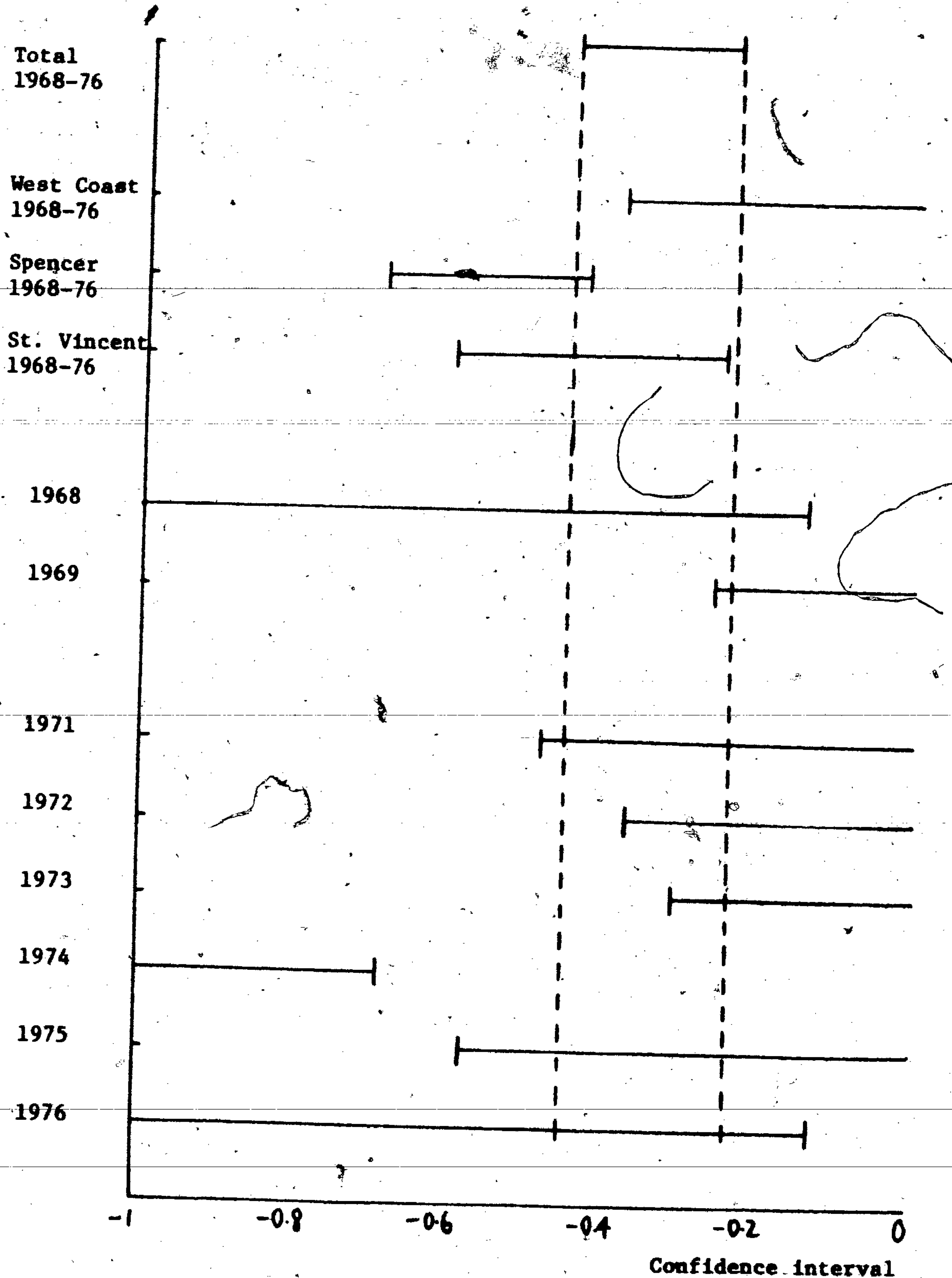


FIGURE 12

95% CONFIDENCE INTERVAL FOR LEARN COEFFICIENT

USING TOTAL, REGIONAL AND YEARLY DATA



offsetting and hence had little effect on the relative fishing power estimates.

The vessel characteristics adopted for the "standard" vessel are somewhat arbitrary, but for realism and to assist in later cost estimation, some correspondence with the actual vessels used in a region was considered sensible. The following were therefore adopted:

West Coast and Spencer Gulf fleet - 16 metre, 250 BHP and double rig,

Gulf St. Vincent and Investigator Strait fleets - 13 metre, 160 BHP and single rig.

The fishing power of the West Coast and Spencer Gulf standard vessel was 58% greater than that of the Gulf St Vincent and Investigator Strait standard vessel.

As at 1977, fishing powers of individual vessels in terms of the above varied from .61 to 1.46 in the West Coast and Spencer Gulf, from .86 to 1.10 in Gulf St. Vincent and from 1.08 to 1.61 in Investigator Strait. This indicates the relative homogeneity of the Gulf St. Vincent fleet and the great heterogeneity of the West Coast-Spencer Gulf fleet.

Using equation (D.I.1), aggregate yearly effort levels for each region in standard vessel hours were calculated. They are shown, together with the unadjusted hours trawled, in Table IX. Note the gradual increases in the effective effort levels per hour trawled for both main fleets. From 1968 to 1977 these increases totalled 19.9% and 30.5% respectively for the Spencer Gulf and Gulf St. Vincent fleets, and occurred despite the attempts to curtail vessel capacity outlined in Section B.II.

It is likely, however, that the above adjustments still overestimate relative effort in early years because of the inability to take account of improved skipper and crew skill and technological developments in gear and equipment.[1]

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[1]See King (1978, 51-52).

IV. STANDARDIZATION OF EFFORT FOR INTRA-YEAR DISTRIBUTIONAL CHANGES

So far it has been assumed that identical patterns of exploitation occurred in all years with respect to seasonal variation in abundance. This is in practice unlikely to be the case. There have in fact been obvious changes in the within-year distributions of effort within each region. What are needed are the standard effort pattern equivalents of the observed yearly effort levels, that is those yearly effort levels required to take the observed annual catches with a standard within-year effort distribution.

The most realistic standard effort pattern to assume for a region is one based on actual practices. The average seasonal effort patterns for each region have already been derived in Section B.V. The problem is how to deduce the yields which would have been taken with these standard effort patterns from the yields taken with the effort patterns actually adopted.

Prawn stocks exhibit very strong natural mortality cycles, hence suggesting that the major part of the within-year abundance cycle is due to natural factors. This is supported by the estimates made by King (1978, 126) of the natural and fishing mortality rates for the Spencer Gulf stock and the observed stability of the seasonal abundance cycle in Spencer Gulf despite significant changes in the seasonal effort pattern.[1] It was therefore considered realistic to assume that observed monthly catch rates would be unaffected by redistribution of effort to meet the standard patterns.

It follows that standard effort pattern equivalents of the actual yield levels for each region and period could be calculated from:

$$(Y/X)t = \sum_{j=1}^{12} Mj\ (Y/X)jt \qquad \text{(D.IV.I)}$$

that is

$$Xt = Yt \,/\, \left(\sum_{j=1}^{12} Mj\ (Y/X)jt \right)$$

where:

Yt = the actual catch level in year t

Xt = the effort level required to take Yt assuming a standardised effort pattern

Mj = the standard effort share in month j of any year

(Y/X)jt = the actual catch rate in month j of year t.

Because the procedure made use of actual monthly catch rates it could only be applied in years when observations were available for all months. This precluded its use for the West Coast in 1968, 1969, 1971, 1972, and 1973, Gulf St. Vincent in 1968 and Investigator Strait in 1975.

The adjusted effort levels by year and region are shown in

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[1] See Section B.V.

Table IX. The major impact was in Spencer Gulf where effort has gradually become more concentrated in the period of maximum prawn abundance.

The other factors determining the abundance of the exploited stocks within a given region and year are the areas and depth where trawling is undertaken. Since only bottom trawling has been undertaken in the fishery, no adjustment for changes in this factor is necessary. However it is likely that there have been changes between years in the within-region locations of trawling. Unfortunately little information on such changes is available. It has been suggested that operators in Gulf St. Vincent have increased their effort in locations closer to the nursery areas where prawns are smaller but more abundant.[1] This is consistent with the observed decline in the price differential for prawns from this region.[2] Unfortunately, however, no quantitative adjustment for this factor was possible.

The affect of this trend would be to increase the rate of fishing mortality, and hence effective effort, for a given number of hours fishing. It is therefore likely that relative effort levels in Gulf St. Vincent in early years were somewhat less than estimated.

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[1]This opinion was expressed by one of the operators during discussion with the author.

[2]See Section B.VI.

TABLE IX

FISHING EFFORT STANDARDISED FOR CHANGES IN VESSEL FISHING POWER AND SEASONAL DISTRIBUTION OF FISHING BY REGION FOR YEARS 1968 TO 1977

West Coast

Year	Actual hours trawled	Standard vessel hours trawled	Standard vessel standard distribution hours trawled
1968	257	137	n.a.
1969	2800	2620	n.a.
1970	9987	8738	8380
1971	8345	6717	n.a.
1972	8907	8176	n.a.
1973	9276	9043	n.a.
1974	5306	4834	5021
1975	6081	6299	6438
1976	3562	2539	2511
1977	1393	887	1050

Spencer Gulf

Year	Actual hours trawled	Standard vessel hours trawled	Standard vessel standard distribution hours trawled
1968	6795	5911	4918
1969	12409	11205	11149
1970	15342	14620	14343
1971	17681	16814	16478
1972	21807	20651	20795
1973	25145	24667	24494
1974	28625	29598	28295
1975	38542	38156	38118
1976	42726	44947	45262
1977	40901	42659	44963

TABLE IX continued

Gulf St. Vincent

Year	Actual hours trawled	Standard vessel hours trawled	Standard vessel standard distribution hours trawled
1968	371	280	n.a.
1969	1215	1063	1016
1970	2813	2453	2537
1971	5750	5273	5295
1972	8179	7778	7929
1973	8037	7687	7745
1974	7982	7594	7687
1975	10360	10177	10232
1976	11758	12388	12398
1977	10137	9966	10031

Investigator Strait

Year	Actual hours trawled	Standard vessel hours trawled	Standard vessel standard distribution hours trawled
1976	4333	5143	5215
1977	4011	4797	4821

E. ESTIMATION OF THE OPTIMUM LEVEL OF EXPLOITATION

I. INTRODUCTORY COMMENTS

As concluded in Section C.I, the South Australian prawn stocks are being exploited in a most efficient manner when the economic surplus generated from each stock is maximised in each period, this surplus consisting of consumer and producer surpluses and resource rents.

To calculate these optimum positions, it is necessary to estimate, for each period,

1. The demand function for the yield derived from the exploitation of each stock,
2. The cost function for fishing effort applied to each stock,
3. The yield function for each stock.

However, as the future is unknown, these estimates must be based on observations of present and past conditions only, and so are at best somewhat approximate. It follows that conclusions based on such estimates must also be considered tentative. Management should therefore always be ready to alter policies to take account of improved knowledge as to the nature of these functions and also of changes in the functions themselves.

As discussed in Section C.I, most economic models of fisheries exploitation have highlighted resource rents only, by assuming perfectly elastic demand and cost functions. This approach will be initally followed in this study also. However, qualitative estimates of the direction of bias introduced by ignoring the other components of the total economic surplus will also be made.

Rather than try to predict the future, the analysis will concentrate on estimates of current revenue and cost functions for the fishery. Comments will then be made concerning the type of adjustment necessary to take account of changes in the relative rates of increase of revenue and cost levels.

II. YIELD CURVE ESTIMATES

As discussed in Section C.II, from a biological viewpoint individual yield curves should be estimated for each separate stock in a fishery. Although there are four fishing regions in the South Australian prawn fishery, the West Coast, Spencer Gulf, Gulf St. Vincent and Investigator Strait, it is likely that there is interaction between the populations inhabiting Gulf St. Vincent and Investigator Strait.

Based on the generally observed southerly movement of prawns in Gulf St. Vincent, it is considered that a large share of the catch in Investigator Strait originates in more northerly areas. This is supported by the fact that in both 1976 and 1977 the Investigator Strait catch rate peaked in May, several months after the exit of juveniles from the nursery areas. This suggests that the catch rate in the strait is dependent not only on the effort level there, but also the effort level in Gulf St. Vincent. Only if the latter is constant, which it has not been, can a separate yield curve for the former be estimated from observed catch and effort levels.

Similarly, if there is also significant movement of prawns from Investigator Strait into Gulf St. Vincent, the catch-effort combinations in the latter region before the development of the Investigator Strait fishery will not be directly comparable with those in more recent years because of the effect on Gulf stock levels of the dramatic expansion of catch in the Strait. If such movement did occur, one would expect a marked decline in Gulf St. Vincent catch rates in 1976 and 1977. The absence of such a decline provides strong evidence that St. Vincent stock levels are independent of effort levels in Investigator Strait. It follows that Gulf St. Vincent catch-effort combinations for the period before the development of the Investigator Strait grounds are comparable with the more recent combinations.

The estimated yearly yield-effort combinations for each of West Coast, Spencer Gulf, Gulf St. Vincent and Investigator Strait are listed in Table X. Because of the exploratory nature of the 1968 operations on the West Coast and in Gulf St. Vincent, the observations for this year in these regions were excluded when estimating the yield curves for these regions. In addition, because the extremely high 1974 catch rate in Spencer Gulf was considered to be due to abnormally favourable environmental factors, and was therefore unsustainable, it was also omitted from further analysis. The remaining observations for each of the established regions are plotted in Figures 13, 14 and 15.[1]

The yield equations derived theoretically in Section C.II, namely equations (C.II.15) and (C.II.16), were applied to the

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[1]Disregard the right hand axis at this stage, its significance will be explained at a later stage.

TABLE X

CATCH, EFFORT AND CATCH PER UNIT OF EFFORT BY REGION FOR YEARS 1968 TO 1977

Year	West Coast Catch (kg.)	West Coast Effort (hrs.)	West Coast C/E	Spencer Gulf Catch (kg.)	Spencer Gulf Effort (hrs.)	Spencer Gulf C/E
1968	8,000	130	55.6	384,000	4,920	78.0
1969	99,000	2,620	37.8	357,000	11,150	49.9
1970	237,000	8,620	27.5	816,000	14,340	56.8
1971	273,000	6,720	40.7	936,000	16,480	56.8
1972	214,000	8.180	26.1	1,076,000	20,780	51.7
1973	290,000	9,050	32.0	1,485,000	24,490	60.3
1974	205,000	4,950	41.4	2,521,000	28,300	89.0
1975	157,000	6,640	23.5	1,736,000	38,190	45.5
1976	51,000	2,540	20.0	2,130,000	45,260	47.0
1977	13,000	1,070	12.4	1,936,000	44,960	43.0

Year	Gulf St. Vincent Catch (kg.)	Gulf St. Vincent Effort (hrs.)	Gulf St. Vincent C/E	Investigator St. Catch (kg.)	Investigator St. Effort (hrs.)	Investigator St. C/E
1968	5,000	280	18.8			
1969	41,000	1,010	40.9			
1970	106,000	2,540	41.7			
1971	162,000	5,300	30.6			
1972	244,000	7,930	30.7			
1973	276,000	7,750	35.6			
1974	370,000	7,690	48.0			
1975	341,000	10,230	33.2			
1976	511,000	12,400	41.2	146,000	5,220	28.0
1977	387,000	10,030	38.5	143,000	4,820	29.6

FIGURE 13

YIELD, REVENUE AND COST CURVES FOR
WEST COAST REGION

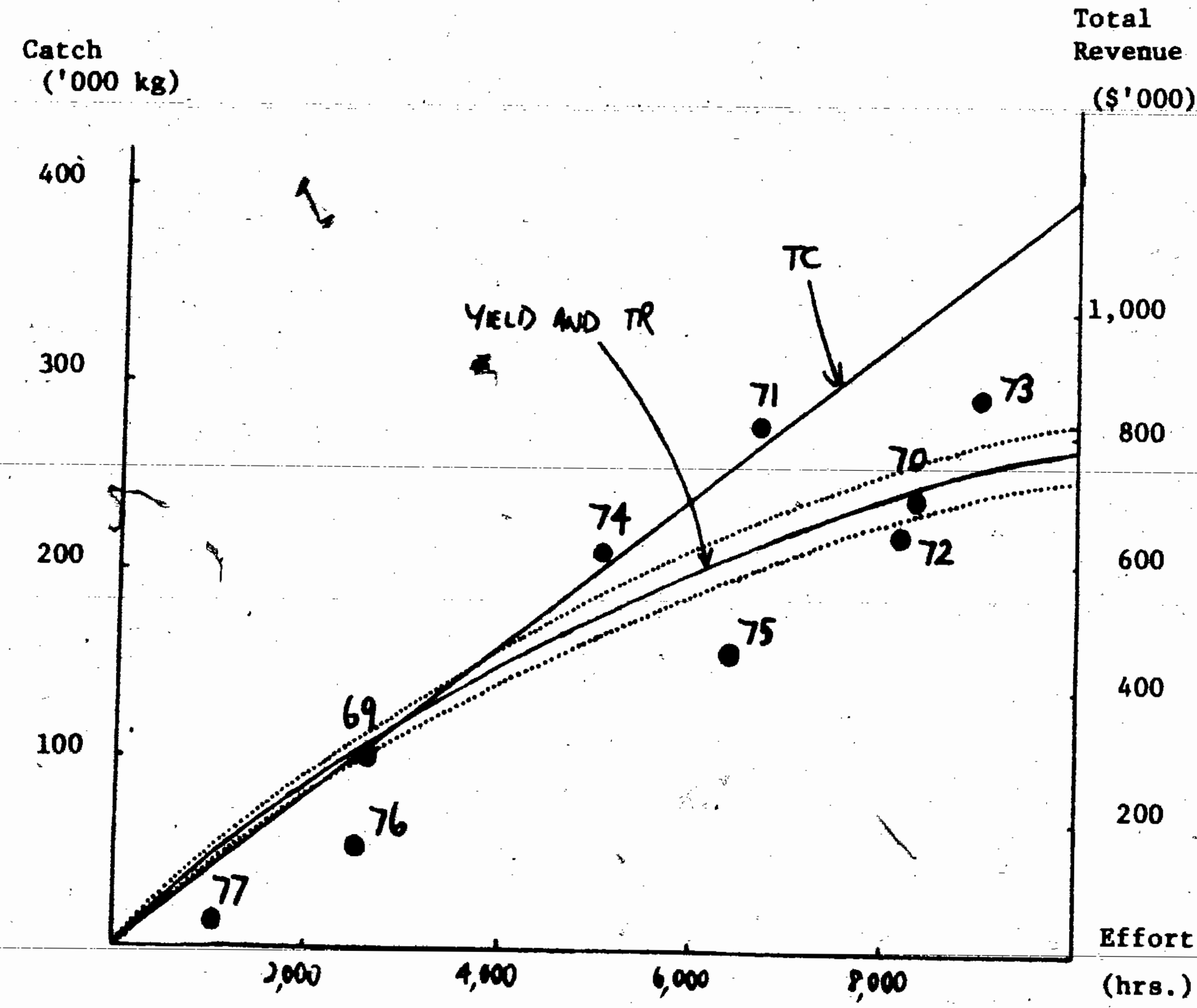


FIGURE 14

YIELD, REVENUE AND COST CURVES FOR SPENCER GULF REGION

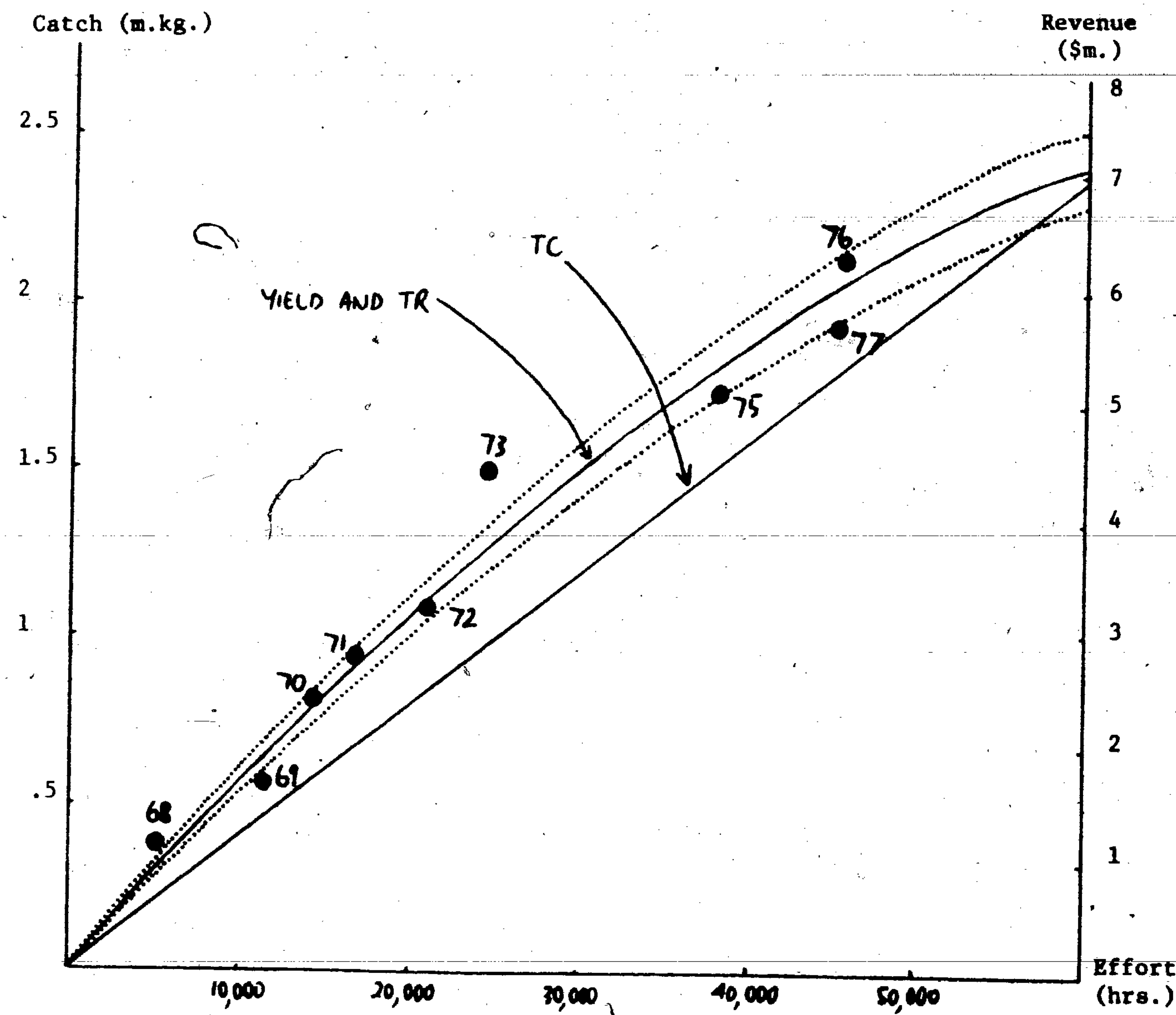
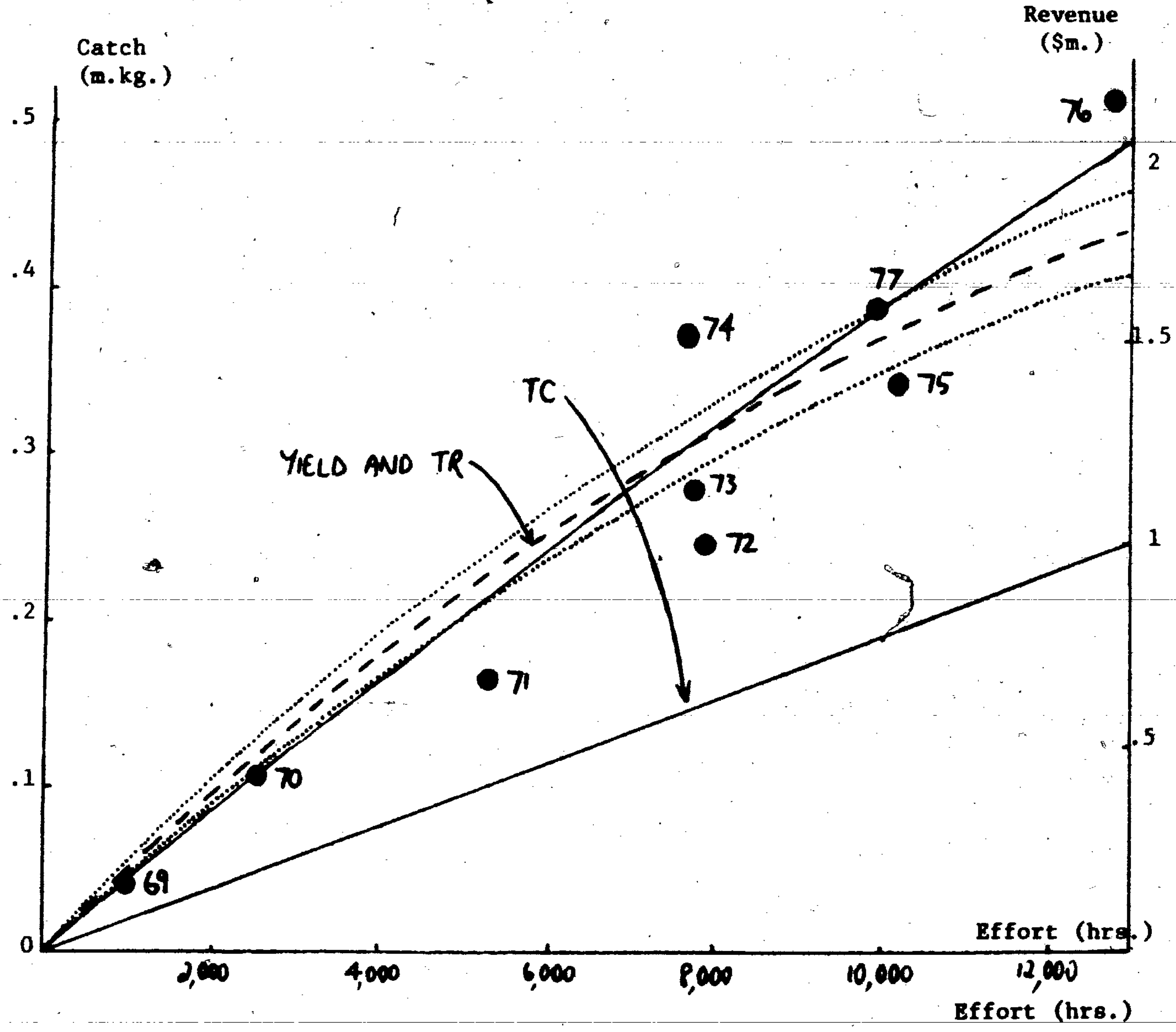


FIGURE 15

YIELD, REVENUE AND COST CURVES FOR GULF ST. VINCENT REGION



plotted yield-effort combinations. The results are given in Table XI. Because of the very limited number of observations for Investigator Strait and its inter-dependence with Gulf St. Vincent, estimation of its yield curve was not attempted.

The hypothesised equations both provided an extremely good fit for Spencer Gulf. In addition, all of the coefficients were in the required ranges. In fact the two equations led to almost identical yield curves over the observed effort range.

For Gulf St. Vincent, the double log equation again explained almost all of the observed yield-effort variation whilst the fit provided by the asymptote equation was also adequate. The estimated coefficients also had acceptable values. The curves implied by both equations had more gradual rates of decline in their slopes than did those for Spencer Gulf, and were not significantly different from straight lines through the origin.

Although the double log model had slightly greater explanatory power for both gulfs, the asymptote based equations were adopted for further study because of their greater theoretical correctness. The estimated yield equations, in their original form were:

1. For Spencer Gulf

$$Y = 3800000\ (1 - .999983^{Xs}) \qquad \text{(E.II.1)}$$

2. For Gulf St. Vincent

$$Y = 85000000000\ (1 - .99999999996^{Xv}) \qquad \text{(E.II.2)}$$

TABLE XI

ESTIMATED REGIONAL YIELD CURVES

Equation (C.II.16): $\log (1 - Y/a) = B X$

Region	a	B	t stat.	R^2
W. Coast	n.a.	n.a.		
Spencer	3,800,000	-.0000170	33.10	.971
St. Vincent	85,000,000,000	-.000000000441	21.36	.919

Equation (C.II.15): $\log Y = a + b \log X$

Region	a	t stat.	b	t stat.	R^2
W. Coast	0.62	0.5	1.319	8.2	.907
Spencer	6.04	11.9	.792	15.5	.972
St. Vincent	3.98	6.5	.959	13.7	.964

where:

Xs = Effort level in Spencer Gulf in West Gulf and Spencer Gulf standard vessel units

Xv = Effort level in Gulf St. Vincent in Gulf St Vincent and Investigator Strait standard vessel units.

The corresponding yield curves are shown in Figures 14 and 15 respectively.

Note that relative effort levels in early years were probably less than estimated, because of imperfect standardisation for changes in fishing power and relative abundance of the exploited subsections of the available stocks.[1] The error is likely to be greatest in Gulf St. Vincent because of the recent move towards greater exploitation in areas of maximum stock density. When combined with the general increases in effort over time, this over-estimate has had the effect of reducing the apparent catch rate decline at higher effort levels. The possible position of the true yield curve for Gulf St. Vincent is indicated by the broken line in Figure 15. Because of this under-adjustment, it was considered that only the Spencer Gulf equation gave a reasonable estimate of the true yield curve.

For the West Coast the fit of the double log equation was inferior to that given for the gulfs, but more importantly, the

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[1] See Sections D.IV and D.V.

value of b was greater than one, implying an increasing rather than decreasing slope, a result which is biologically impossible. The optimum asymptote in the asymptote equation was undefined, with the explanatory power of the equation increasing continuously with increases in a.

The unusual shape of the estimated West Coast yield curve suggests that the observed annual catch-effort combinations on which it was based do not represent sustainable positions. This appears to conflict with the fact that prawns are considered an annual crop. However, the annual crop concept is to some extent an over-simplication. Depending on the level of fishing, adult prawns may live for up to three years. The greater the level of exploitation the lower the average age of prawns in the stock. It would appear that the observed West Coast combinations lie on two separate short-run yield curves.[1] The first covers the period up until 1973, during which effort was expanding. Here catch rates were above sustainable levels due to the presence of large numbers of older and larger prawns not captured during earlier years, when the region was fished less intensively. After 1973, because of the prior high levels of exploitation, not much more than one year class of prawns was present and this had the effect of significantly reducing the catch rate, even though effort had also declined considerably. An alternative

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[1]The relationship between short-run and long-run yield curves is outlined in Copes (1978, 25-27)

explanation is that the effort level was sufficiently high in the early 1970's to reduce the parent stock below that required to maintain the previous recruitment levels, despite the very high fertility of the species. Both explanations suggest that the sustainable yield curve is somewhere between the 1969-74 and 1975-77 yield-effort paths. A possible sustainable yield curve is shown in Figure 13.

The above reduction in average age of prawns caught has, of course, also occurred in other regions to some extent. However, it has been largely taken into account, especially at high effort levels, by the maintenance of effort at these levels for a number of years.

Note that the estimated yield curves are at best approximate. In addition, they represent average positions only. As discussed in Section B.III, the annual rate of regeneration, and hence the yield at a given effort level for each stock is subject to significant random variation.

It is, therefore, perhaps more realistic to think in terms of a yield band rather than a single curve for each stock. Such bands are indicated by the dotted lines on either side of the estimated yield curves in Figures 13 to 15. For illustrative purposes a 5% variation on either side of the estimated yield levels has been used.

III. COST AND REVENUE CURVE ESTIMATES

Virtually all of the prawn catch is purchased by local processing companies, with a small group taking the bulk of the catch. These processors in turn sell largely to the world market, to which South Australia is but a very small supplier. Competition between the processors is such that they operate on essentially a markup basis.

As a result of these factors, fishermen normally face an extremely elastic demand curve for their catch, with the price being dependent on world demand and supply conditions. The annual revenue function for each region is therefore accurately reflected by a function of the form

TRt = Pt Yt (E.III.1)

where:

TRt = the total revenue in year t

Pt = the average price per unit of catch.

Note that Pt is affected by the average size of prawns caught, with larger prawns commanding significant price premiums. As discussed in Section B.V, average prawn size in turn depends on the areas and times of fishing. Given that the estimated yield curves have already been based on the normal fishing practices in each region, for consistency, price estimates were based on normal size compositions of catch also.

Estimates of average yearly prices in each region are shown in Table V. Note the variability of prices in all regions caused by random fluctuations in world demand and supply.

In order to balance out some of the random fluctuations in prices, they were averaged over the three most recent financial years, 1975-76 to 1977-78, leading to the following average price estimates over this period:

West Coast - $2.95 per kg.

Spencer Gulf - $2.95 per kg.

Gulf St. Vincent - $4.07 per kg.

Investigator Strait - $3.54 per kg.

The total revenue equations based on these prices are:

$$TR_w = 2.95\ Y_w \qquad \text{(E.III.2)}$$

$$TR_s = 2.95\ Y_s \qquad \text{(E.III.3)}$$

$$TR_v = 4.07\ Y_v \qquad \text{(E.III.4)}$$

$$TR_i = 3.54\ Y_i \qquad \text{(E.III.5)}$$

where:

TR_w, TR_s, TR_v and TR_i = total revenue in the West Coast, Spencer Gulf, Gulf St. Vincent and Investigator Strait respectively.

Since total revenue is proportional to yield, the yield bands in Figures 13, 14 and 15 can also be used to represent the possible total revenue positions in each region. The monetary scale is indicated on the right hand vertical axis in each figure.

The costs of a fishing enterprise can be divided into three major segments:

1. Operating costs, which are a function of the time spent fishing, for example expenditure on fuel, repairs and maintenance and provisions.
2. Labour costs, which are normally expressed as a percentage of gross revenue.
3. Fixed costs such as licence and other fees, depreciation and cost of capital.

It is traditional in fishing operations for hired skippers and crews to be paid on a share-of-revenue basis,[1] and this practice is normal in the South Australian prawn fishery. Possible advantages are that it improves efficiency, and that it enables risk to be shared between owner and crew.[2] Griffin et al. (1976) have, therefore, argued that labour costs should be regarded as a function of gross revenue rather than time spent fishing.

This line of reasoning, however, ignores the factors determining the share percentages. Whilst in the short run these shares are fixed, their values will be such that expected crew payments the long term are dependant on their wages in alternative employment. It follows in that labour costs are

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[1]See Zoeteweij (1957).

[2]See Crutchfield and Zellner (1962).

essentially a function of the time spent fishing.

Fishing costs can therefore be conveniently divided into fixed and variable components, with variable costs being a function of the period of time spent fishing over a year. That is:

$TC = VC + FC$

and $VC = C(T)$,

where:

TC = total vessel costs for year

VC = total variable costs for year

FC = fixed costs for year

T = operating time of vessel for year.[1]

The cost per unit of fishing effort is given by

$AC = (TC/T)\ FP.$

If it is assumed that each fleet is composed of homogeneous fishing units, each operating in an identical manner, the cost of each unit of fishing effort is the same. That is

$$TC = X\ Cs \qquad (E.III.6)$$

where:

Cs = the cost per unit of effort.

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[1]Assuming a stable within-year effort distribution and area of fishing.

The only independent estimates of vessel operating costs in the South Australian fishery were based on the period 1967-68 to 1969-70[1] and are now very outdated. Recent data are confined to that provided in various submissions or presentations made to the South Australian Government on a voluntary basis by individuals or groups of prawn operators from the West Coast-Spencer Gulf fleet.[2]

These submissions make use of subjective estimates of vessel values and of the alternative incomes of crews and skippers. Given the desire of operators to paint as gloomy a picture as possible of their financial position in order to reduce the likelyhood of new authorities being issued or licence fees being increased, they are likely to overestimate these and possibly other items, hence introducing an upward bias into their cost estimates.

The estimates can, however, be used to illustrate how the economic model can be completed and may give a very broad indication of the directions of adjustment of effort levels which should be considered in each region and the relative resource rent levels of the different regions.

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[1]See Fisheries Division, Australian Department of Primary Industry (1974).

[2]The two major submissions are Western Prawn Boat Owners Association (1975) and Western Prawn Boat Owners Association (1978).

The above submissions claim that costs per unit of effort for the standard Spencer Gulf vessel increased from $85 in 1974-75 to $137 in 1977-78.[1] Assuming uniform rates of cost increases over this period, the corresponding average cost per standard vessel hour over the 1975-76 to 1977-78 period is $118.

Given that the fishing power of the West Coast-Spencer Gulf standard vessel is 58% greater than that of the Gulf St. Vincent and Investigator Strait standard vessel, this figure is equivalent to $75 per hour trawled for the latter standard vessel.[2]

The resultant total cost equations are:

$$TC_w = 118\ X_w \qquad (E.III.7)$$

$$TC_s = 118\ X_s \qquad (E.III.8)$$

$$TC_v = 75\ X_v \qquad (E.III.9)$$

$$TC_i = 75\ X_i \qquad (E.III.10)$$

where:

TC_w, TC_s, TC_v and TC_i = total costs in the West Coast, Spencer Gulf, Gulf St. Vincent and Investigator Strait respectively

X_w, X_s = Effort in the West Coast and Spencer Gulf in West Coast and Spencer Gulf standard vessel hours

X_v, X_i = Effort in Gulf St Vincent and Investigator Strait in

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[1]The cost estimates were standardised by assuming uniform depreciation rates and returns on capital of 7.5%. and 17.5% of replacement cost of vessels respectively.

[2]The comparability of cost levels in the various regions will be discussed below.

Gulf St. Vincent and Investigator Strait standard vessel units.

Since total cost is directly proportional to effort, the above equations will be represented by straight lines through the origin as shown in Figures 13, 14 and 15.

IV. ESTIMATION OF RESOURCE RENT

By combining the yield, revenue and cost equations for a region, one can estimate the resource rent generated per period at each possible effort level, as outlined in Section C.I.

The technique can be illustrated using the estimated yield and revenue functions and hypothetical cost function for Spencer Gulf. We have

$$Y = 3,800,000 \ (1 - .999983 * Xs)$$

$$TR = 2.95 \ Y$$

$$TC = 118 \ Xs$$

and therefore

$$R = TR - TC$$

$$= 11,200,000 \ (1 - .999983 * Xs) - 118 \ Xs,$$

and

$$dR \ / \ dXs = 190 \ (.999983 * Xs) - 118,$$

where:

R = the annual economic surplus in dollars.

The surplus will be maximised when

$$dR \ / \ dXs = 0$$

that is when

$$190 \ (.999983 * Xs) = 118$$

This reduces to

$$Xs = 32,000.$$

Substituting into the yield and revenue equations this gives

Y = 1,600,000

and

R = $940,000.

It is interesting to compare the above results with the current rents levels implied by the same set of equations. Given the current effort level of approximately 45,000 standard hours, current catch would be 2,030,000 kg., and resource rents $680,000, an average of over $17,000 per vessel authorised to trawl in Spencer Gulf.

The yield curve band resource rent ranges corresponding to the above optimum and current positions are shown in Table XII. Note the extreme sensitivity of the rent estimates to changes in the yield curve position. The results are similarly very sensitive to changes in price or unit cost levels. A variation in yield of only 5% at current effort levels alters the resource rent per kilogram of catch by $.14, half the estimated current level of $.28.

Based on these estimates, it would appear that effort levels in Spencer Gulf are currently past the level which would maximise resource rents. The optimum effort level, however, is also very sensitive to changes in the position of the yield curve. It follows that the extent to which effort levels in 1975 to 1977 have been past the resource rent optimum also depends very much on the position of the yield curve in each particular

TABLE XII

HYPOTHETICAL RANGES FOR CURRENT AND OPTIMAL RESOURCE RENT LEVELS FOR SPENCER GULF

	At lower bound	At upper bound
Estimated yield at hypothetical optimum effort of 32,000 hours (kg).	1,520,000	1,680,000
Corresponding total revenue ($)	4,480,000	4,960,000
Corresponding total cost ($)	3,780,000	3,780,000
Implied resource rent ($)	700,000	1,180,000
Estimated yield at current effort of 45,000 hours (kg).	1,920,000	2,130,000
Corresponding total revenue ($)	5,660,000	6,280,000
Corresponding total cost ($)	5,310,000	5,310,000
Implied resource rent ($)	350,000	970,000

year. The alternative rent levels are shown by the vertical distances between the total revenue and total cost curves in Figure 14.

Because of the subjective nature of the estimated West Coast and Gulf St. Vincent revenue curves and the additional uncertainty of cost levels in the latter region, estimates of the rent levels and hence optimum effort levels for these stocks are very rough. Some very tentative conclusions can however be drawn from the subjective revenue and hypothetical cost curves shown in Figures 13 and 15.

It would appear that the Gulf St. Vincent stock is currently being much less heavily fished than the Spencer Gulf stock and that resource rents are likely to increase with increased effort. Using the hypothetical cost levels described above and the suggested yield curve band, current resource rent levels are between $680,000 and $830,000. This represents an average of $49,000 to $59,000 for the fourteen authorised vessels, or $1.80 to $2.20 per kg. of catch. Note that these vessels are smaller and hence represent much lower capital investments than those in Spencer Gulf, yet achieve much higher average resource rent levels on a per unit basis.

A further interesting result can be deduced from a comparison of the resource rent range for vessels operating in the two major regions. In Spencer Gulf, where the resource rent represents a much smaller part of the total revenue, it is much more sensitive to changes in the underlying variables than in Gulf St. Vincent and hence operators in the former region face considerably higher profit variations.

It would appear that the West Coast stock is relatively small and cannot withstand continuous exploitation at the high effort levels of the early 1970's. Even at a much lower effort level of say 2,000 to 3,000 hours, it is unlikely to generate significant resource rents.

Resource rents in Investigator Strait, given the current catch of 145,00 kg. in 5,000 standard hours trawling and the hypothetical cost levels outlined above would appear to be between $70,000 and $120,000, distributed between five permit holders. This represents $.48 to $.83 per kg. of catch. No suggestions as to how effort should be adjusted can be made for this region.

The major conclusions from the above analysis are:[1]

1. Resource rents in Spencer Gulf could possibly be increased by some effort reduction.

2. Resource rents in Gulf St. Vincent could almost certainly be increased by an increase in fishing effort.

3. A large reduction in fishing effort from the levels achieved in the early 1970's is warranted on the West Coast.

4. The relative rent levels per unit of catch at current effort

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[1]Note that these conclusions are tentative, and are considerably modified in Section E. V.

levels are highest in Gulf St. Vincent, considerably lower in Investigator Strait and somewhat lower still in Spencer Gulf.

5. The relative rent levels on a per vessel basis at current effort levels are again highest in Gulf St. Vincent but are higher in Spencer Gulf than Investigator Strait. In addition the differences between regions is considerably less than in the rent per unit of catch comparison.

6. The level of resource rent per unit of catch from a region is extremely sensitive to changes in the position of the yield curve and prices and unit effort costs.

7. The optimum effort position for a region is also very sensitive to changes in the position of the yield curve or in price or unit effort cost levels.

V. QUALIFYING CONSIDERATIONS

The above results assumed that vessels operating in all regions had identical costs per unit of fishing effort. It is considered that in fact vessels had higher costs per unit of effort in Gulf St. Vincent than in Spencer Gulf for the following reasons:

1. Vessels in Gulf St. Vincent are confined to use of single rig, despite the accepted superiority of double rig.
2. Vessels in Gulf St. Vincent fish for shorter periods per year and hence must spread fixed costs over a smaller number of hours.

The high costs in Gulf St. Vincent were accompanied by high revenue derived from each unit of effort. Of course, the high costs do reduce the potential rent for a given fishing effort by keeping costs higher than necessary in relation to revenue.

However, it is considered that the best strategy for this region is not to base policy on existing inefficient methods of operations but rather to encourage adoption of superior fishing techniques. There is little doubt that resource rents from the region would be increased by efficiency improvements in each of the above areas, even if they were accompanied by some increase in effort, since current effort in this region is far from excessive.

The West Coast fishery is primarily based on part-time exploitation by Spencer Gulf operators during periods of low catch rates in the gulf. They are primarily concerned with covering their variable costs, fixed costs having been met during the main season in the latter region. Since variable costs represent only about two thirds of total costs, the relevent cost curve for the West Coast when fished in this manner is considerably lower than that derived above, which assumed full-time operation.

If fished on a part-time basis, effort levels of about 4,000 to 6,000 hours may be justifiable for the region. Some rents may also be generated in such a situation, although they are likely to be fairly small.

The analysis so far has also not taken into account the size of the consumer and producer surpluses generated at each level of exploitation.

Consumer surplus equals the difference between what buyers are willing to pay and the market price. It accrues to the final consumers of a good. Since about 90% of the South Australian prawn catch is exported, most of the consumer surplus associated with it accrues to individuals outside the state of origin. Assuming that the aim of resource management is to maximise the benefits derived from the fishery in South Australia alone, the consumer surplus gained by other groups can be ignored.

The price in the domestic market depends almost solely on export prices, and hence is unlikely to be affected by changes in effort and hence catch levels. Any local consumer surplus is therefore also independent of the catch level.

It is therefore concluded that taking account of consumer surplus has no impact at all on the analysis.

It has already been argued that the estimates of outlays made and receipts foregone provided voluntarily by fisherman probably contain biased information. If they are based on the operations of the least efficient participants they will also over-estimate the market costs of all more efficient operators. In view of the heterogeneous nature of the vessels within the Spencer Gulf fleet and the variation in number of hours worked, the distortion introduced by this effect could be quite considerable.

In addition, as discussed in Anderson (1978), because of the rather unique nature of the fishing activity itself, it is considered that participants derive some psychic income from it above their market remuneration, hence use of wages foregone as a measure of labour costs overstates true cost levels.

To the extent that the hypothetical cost levels used in the analysis overstated the actual costs per unit of effort, the estimates of desirable effort levels will be biased downwards.[1]

If costs per unit of effort decrease relative to the price of the catch, that is if relative costs decline, then the optimum level of exploitation for a given stock will increase. Hence if it is considered that over time relative costs of prawn fishing will decrease, a gradual expansion of the level of effort will be warranted, even if current effort levels appear to be satisfactory.

It is difficult to predict the relative rates of increase of prices and unit effort costs in the prawn fishery. However, to the extent that fishing technology is continuously improving and the world is becoming more affluent and so increasing its demand for luxury foods such as prawns, it would appear that an increase in relative prawn prices is probably likely in the future.

Taking these factors into account, it would appear that there is probably little to be gained by reducing Spencer Gulf effort at this time but that there is considerable social benefit from expansion of effort and catch in Gulf St. Vincent, especially if unit cost levels are also reduced. The desirable effort level on the West Coast will be somewhat larger if vessels switch to it on a part-time basis from Spencer Gulf, rather than operate there on a full-time basis. However even in

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[1]See Copes (1972).

the latter case, it would appear that effort levels of the early 1970's were excessive.

VI. REGULATION OF PRAWN CAPTURE SIZE

The discussion so far has taken the manner of exploitation of the stocks and hence the average size of prawns caught in each region as given, although the differences between regions have been taken into account. Different revenue and cost curves result from each possible pattern of exploitation. In theory an ideal regulation strategy for each region based on the characteristics of each particular stock could be developed. It would need to take into account the numerous factors affecting the yield, revenue and cost functions.

The benefits of any particular regulation will depend on:

1. The costs of enforcement and its effectiveness.
2. The rates of growth and natural mortality of prawns over the season.
3. The relative prices of prawns of various size classes.
4. The rates at which prawns disperse after leaving the nursery areas and hence the rates of change in capture costs as average size increases.
5. The extent to which fishing costs are fixed and hence to which average costs per unit of fishing effort increase as the period of vessel usage in the year declines.

King (1978, 131-33) suggests that at least for Spencer Gulf the weight of prawns is maximised if they are taken at a size slightly smaller than that at which they leave the nursery areas. However, because of the significant price differential which exists for larger prawns and their rapid rate of growth during the summer months, it would appear likely that the value of the catch will be greater if capture occurs perhaps two or three months later.[1] This lends support to some type of seasonal closure early in the season.

On the other hand a shorter fishing season will decrease the period over which vessels will be utilised, assuming the current requirement that operators not participate in other fisheries continues to apply. This will increase average fixed costs per unit of time spent fishing over the remainder of the year.

In addition, the general dispersion of prawns after they exit from the nursery areas should decrease catch rates, further increasing the cost of taking each unit of catch.

The combining of the above factors into a total economic model, even if all the necessary data were available, is a complex problem and will not be attempted here.[2]. Some very general comments about the simplest form of seasonal regulation, the setting of opening dates for the fishing seasons in

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[1]Based on very rough unpublished estimates by King.

[2]Formulation of a much simplified model, ignoring dispersion and price differential factors, has been attempted by Bradley (1969).

particular regions, can however be made.

Whatever type of seasonal closure is attempted, individual fishermen may benefit by cheating. Such cheating reduces the possible benefits from regulation and also encourages other operators, who initially abided by the closure, to also cheat, which further reduces the potential overall benefits. The practicality of the closure is therefore a very relevant consideration. For this reason the current closure of only a part of Spencer Gulf from mid-January to mid-March is far from ideal because the difficulty of monitoring where vessels are actually fishing leads to frequent violations. [1] A much simpler policy is total closure of all areas. This could be policed much more easily, by ensuring that no prawn vessels are in operation during the closure period.

Neal (1975, 5) suggests that useful evidence as to the possible benefit of a seasonal closure may be provided by comparisons of:

1. The profitability of exploitation of a given stock in different years when the patterns of expoitation have been different,

2. The profitability of exploitation of two different stocks where the patterns of exploitation differ,

3. The profitability of exploitation of a given stock under

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[1] See SAFIC (Aug. 1977, 38)

varying forms of regulation.

The most useful suggestion for South Australia is probably 2. Gulf St. Vincent operators earn much higher rates of return than do operators in Spencer Gulf. Although this is due partly to the less intensive exploitation and hence higher catch rate in Gulf St. Vincent, it is also contributed to by the large price differential for catch taken in this region. As discussed in Section B.V, this is largely because of the larger average size of prawns caught in this region, which is in turn due to a more balanced within-year effort distribution and the fact that operators fish in areas well away from the nurseries.

The above analysis suggests that management should attempt to achieve this manner of exploitation in Spencer Gulf also. This would entail limiting effort early in the season and prevention of trawling in areas adjacent to the nurseries. Unfortunately, the latter type of restriction has already proved to be largely unworkable. Complete closure of the whole region for the two or three months during and immediately after the period of peak recruitment would be easier to implement and would avoid the taking of large numbers of small prawns, but it would significantly shorten the fishing season and hence lead to a marked decline in the efficiency of usage of the available vessels.

A system of intermittent total closures is perhaps the best compromise solution. A short total closure early in the season, from say 15 January to 15 Febuary could be fcllowed by a system of closed and open days or groups of days for perhaps the next six weeks. The ratio of open to closed days could be gradually increased to achieve stepped increases in effort as the season progresses. Towards the end of the season controls could be removed altogether, so as to maximise the catch of the large, higher priced prawns.

This system, because it is based on total closures, would be easy to police and would avoid excessive effort early in the season whilst allowing some fishing during almost all months of the year. The rate of transition through the three stages could, of course be modified on a yearly basis in the light of biological information derived from either sample trawling in or near the nursery areas or examination of the composition of the catches taken during initial weeks of fishing. For example if the time of recruitment was later than usual or if the level of recruitment appeared to be fairly low, the rate at which the closures are relaxed could be slowed down.

The benefit of the scheme, in terms of total rent from Spencer Gulf, is very difficult tc estimate. Slightly lower effort and catch levels are likely, however, since effort is if anything slightly obove the optimum, this is a desirable trend. Catch rates later in the year should increase, although the overall catch rate for the year will almost certainly be reduced because of reduced effort during the peak abundance months. This should be more than compensated for by the increase in the average price received for each unit of catch. It is the author's guess that the overall result would be a small, but not insignificant, total rent increase.

F. ALLOCATION OF ACCESS RIGHTS AND DISTRIBUTION OF RESOURCE RENTS

I. THE CHOICE OF THE ACCESS RIGHT UNIT

The level of exploitation of a fish stock can be defined in terms of either catch or effort, since they are directly related through the yield function. In terms of trying to achieve a particular level of exploitation by the application of a limited entry scheme, however, the results may be significantly effected by whether the access rights of individual participants are specified in catch or effort terms.

In attempting to achieve the desired level of exploitation of a fish stock, management can follow either of two basic stratagies. It can limit the catch of each participant directly, by means of catch quotas, or indirectly via the use of effort restrictions or quotas. As discussed in Section D. I, the fishing effort of a participant depends on the number of fishing units he uses, their fishing powers, how much they are used and on which stock segments they are used, hence all schemes based on limiting the fishing effort of each participant entail restriction of one or more of these parameters.

In a limited entry fishery, assuming that some resource rents are being generated, at the margin the fishery is still yielding a positive private surplus. It follows that participants have an incentive to try to increase their fishing efforts and hence catches. Assuming that total effort is at or past the optimum, such increases would reduce the rents being generated by the fishery. In addition, since they allow individual operators to capture additional resource rents, although it is at the expense of other operators, they may be undertaken even if they increase their costs per unit of effort. Such unit cost increases would also reduce the rent generated by the fishery. Increases in fishing effort tend to occur because of the difficulty of achieving perfect control of the effort or catch levels of individual operators.

Consider the case where each operator is given an effort quota in terms of a vessel-year, that is, he is permitted to use a single vessel, but can otherwise fish as he wishes. He is likely to attempt to increase his effective effort per unit of nominal or controlled effort by adjusting his non-controlled inputs such as vessel size, number of crew, type of gear, time spent fishing and areas fished. To the extent that such changes alter his input mix for the fishing operation from the most efficient one, they will increase his costs of achieving a given effort level.[1]

The usual strategy adopted by management to prevent effective effort increases is to specify the effort quota in

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1- This effect is widely known and is discussed in numerous studies of limited entry schemes. See for example Anderson (1976), Christie (1973, 34-5), Copes (1978, 10-11 and 80-81) and Sinclair (1978, 1024).

terms of more than one parameter. For example the fishing power of vessels may be restricted by regulating its size or the type of gear it can use. In theory this could be done in such a way that all participants would be permitted to adopt most efficient fishing techniques but be unable to increase their effective effort levels. In practice, many adjustments undertaken by operators both increase effective fishing effort and decrease cost per unit of effort, so that it is frequently difficult to determine the overall impact on economic rents for the fishery as a whole. For ease of administrative control, management often finds it convenient to apply blanket restrictions on certain types of modifications to fishing units. Such a policy is likely to achieve reasonable control of the effort of each operator, and hence prevent, or at least minimise, the extent of over-exploitation. However, because it is also likely to prevent the introduction of more efficient fishing techniques, it may increase costs per unit of effort.[1] The overall impact on resource rents from the fishery of such restrictions is therefore unclear.

If the access right is specified in terms of a catch quota, operators may be tempted to cheat on their allocated catches. Such over-quota catches would have to be disposed of in a "black market". To the extent that the operators face additional unit

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[1]See Christie (1977, 152-53)

costs in disposing of catches in this way - these costs may in fact take the form of lower unit prices - the cost of taking a given catch will also be increased.

One efficiency advantage of a catch-quota scheme is that it is not necessary to restrict in any way the fishing methods used by participants, since their effort levels are regulated already in terms of their allowable catches. The inefficient input distortions which occur under effort-quota systems because of attempts by operators to increase their effective effort levels and because of management attempts to prevent such increases are therefore avoided. The cost of taking the quota may still be above the minimum, however, because of the restriction which is placad on each operator's scale of operation. Only if quotas were saleable could unit costs be completely minimised.

In summary, under any limited entry scheme there is a tendency for a gradual erosion of resource rents to occur via increases in the level of effort and concomitant increases in costs per unit of effort. If the number of participants could be readily adjusted, the first trend could be neutralised by gradually reducing the number of participants. However, for reasons which will be developed below, such reductions are usually difficult to achieve.

The choice of the best access right unit in a particular fishery must weigh the possible losses from both an inferior level of exploitation and adoption of inefficient fishing techniques. One particular aspect which may be especially relevent is the ability of the scheme to provide the flexibility necessary to adjust quickly to changes in the desired level of exploitation.

In the South Australian prawn fishery, access rights are currently specified in the form of vessel-years, however several vessel characteristics are also regulated. Although the effective fishing effort level per vessel, in each fleet, has increased considerably since the closing of entry to the fishery, as shown in Table XIII, it would appear that the scope for further such effort increases is limited. Most of the possible strategies have already been followed. In terms of their ability to control the level of exploitation in each region, therefore, the current regulations are probably generally adequate, especially since some further effort increase can probably be accommodated in most regions without an excessive reduction in economic surplus.

There is one obvious exception to the above conclusion, however, the West Coast. It was concluded in Section E.VI that the stock in this region is relatively small and was subject to excessive exploitation during the early 1970's. These high fishing levels were possible because of the ability of operators to switch between it and Spencer Gulf. This potential for over-exploitation should be avoided by terminating this interchange right and introducing specific control of the number

TABLE XIII

AVERAGE ANNUAL EFFORT LEVEL PER OPERATOR IN EACH

FISHING FLEET[1] FOR YEARS 1968 TO 1977

Year	West Coast-Spencer Gulf (hrs.)	Gulf St. Vincent (hrs.)	Investigator Strait (hrs.)
1968	230	93	
1969	492	253	
1970	765	317	
1971	603	530	
1972	805	793	
1973	932	775	
1974	831	641	
1975	1,119	853	
1976	1,138	886	1,043
1977	1,096	717	964

[1]Because operators are free to operate in both the West Coast and Spencer Gulf, the effort levels of operators in each region were combined to give a single overall figure.

of vessels permitted to operate in the West Coast region.

There are three possible ways to exploit the West Coast stocks:

1. Grant a small number of licences specifically for the region, and allow only the holders of these licences to fish there.
2. Allow a limited number of Spencer Gulf operators to fish there on a part-time basis during part of the year only.
3. Have a mixture of some full-time licencees and some part-time operators from Spencer Gulf.

The advantage of full-time operations is that it ensures that a substantial part of the available stock is taken throughout the year. However, because of the need to cover total costs, it is unlikely to lead to any resource rents. Part-time operation, on the other hand, would mean that operators would only have to cover marginal costs and would be fishing previously unexploited stocks and hence achieving improved catch rates, both of which should significantly improve returns from West Coast operations. In addition this strategy would decrease the pressure on the Spencer Gulf stock during the period of lowest catch rates, thus improving the catch rates of those operators still fishing in this region.

Whilst the available data are inadequate to allow a definite conclusion as to the best stratagy to be reached, a combination of perhaps two full-time licencees and a small number of about three to six part-time operators from Spencer

Gulf may be a reasonable compromise stratagy. It would allow some of the benefits of both full-time and part-time exploitation to be achieved.

It is difficult to assess the inefficiencies which have been introduced by the current regulations with respect to vessel length and net size since the relative efficiencies of various input combinations are largely unknown.

It is likely that one advantage of a larger vessel would be greater carrying capacity and hence less frequent need to return to port for unloading. This advantage would be greater when the grounds are more distant from the home ports or unloading ports. Given that the Spencer Gulf grounds are more distant from such ports than are those in Gulf St. Vincent, the current smaller allowable vessel size in the latter region has some efficiency justification.

One restriction which is clearly hampering efficiency in Gulf St. Vincent is the confinement of all vessels to single rig. It has been estimated that double rig increases vessel catch rates by approximately 30%, yet it entails a much smaller increase in vessel operating costs, hence it is clearly a more efficient type of gear than single rig. In view of the fact that effort is probably under the rent-maximising level in this region anyway, the adoption of double rig is an ideal way to both increase fishing effort and decrease costs per unit of effort.

The adoption of double rig by all vessels should be both permitted and encouraged, if rent is to be maximised. The necessary incentive could be provided by the threat to increase effort by issuing additional licences if current participants fail to increase their effort levels by moving to double rig.

At present there is no regulation of the hours trawled by individual vessels. This means that operators have the flexibility to adjust their effort levels on a short term basis. Whilst operators, acting independently, obviously will not adjust regional effort to the rent-maximising level in each period, provided they attempt to maximise private profits,[1] the direction of adjustment will at least be correct.

A possible alternative to the current system would be the allocation of catch quotas to individual fishermen. Because of the small number of processors, their independence from the fishermen and the eventual sale of the bulk of the catch on overseas markets, it is considered that the government, by monitoring processor company purchases, would be able to accurately check operator catches. There would be little scope for over-quota catches because of the absence of a suitable market. It is therefore concluded that from a control aspect the use of catch quotas is feasible.

One should, however, also consider the yearly economic

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[1] This aspect will be discussed further in a later section.

rents achieved under such a quota system. Prawn stocks are subject to considerable fluctuations in abundance over the years and also exhibit a marked within-year abundance cycle. The total desirable catch will therefore vary significantly among years, and the size of each quota should be adjusted accordingly. In addition, as discussed in Section E.VI, there may also be gains from regulating the within year distribution cf the catch. For example it may be desirable to hold down the catch early in the year when prawns are small and fetch a low price. There is, however, little to be gained by regulating the catch at the end of the season when prawns are large and natural mortality is very high.

The ideal catch-quota scheme should therefore encompass variable catch quotas for part of the year but allow unlimited fishing towards the end of the year to allow as much as possible of the residual stock to be taken. For this type of scheme to be successfully implemented it is necessary to predict at the very beginning of the season the strength of the recruitment and hence the ideal total catch and catch distribution for the year. Unfortunately the biological data necessary for this type of fine tuning is not currently available, and hence precludes use of a catch-quota scheme at this time. Even if the required data were available, it would be difficult to prevent operators with freezing capacity from using it to disguise when catches were actually taken, so as to cheat on their allocated quota for the early part of the season. Hence the scheme would still be difficult to implement.

It is concluded that the current system of allocating access rights in terms of vessel-years should be retained, subject to three provisions:

1. The practice of allowing vessels to interchange freely between Spencer Gulf and the West Coast should be discontinued. Instead, access should be restricted to a very small number of full-time operators and a few Spencer Gulf operators on a part-time basis. 2. The ban on use of double rig in Gulf St. Vincent should be discontinued.

3. Effort in Spencer Gulf should be delayed by the use of intermittent total closures.

II. CLAIMANTS TO THE RESOURCE RENTS

There are two obvious claimants to the resource rents generated by a limited entry program, the actual participants in the fishery and the general public, who are normally considered to be the primary owners of the resource. Whilst the question of rent distribution is largely concerned with equity and is therefore more political than economic, it is worthwhile to clarify at least some of the issues involved. The rent distribution may also have some economic implications.

The major economic argument advanced in support of rent retention by fisherman is that it provides an incentive for greater efficiency and innovation.[1] It is true that if all operators in a fishery reduce their costs per unit of effort by adoption of a more efficient method of fishing this will increase resource rents at a given level of effort and if some rents are retained by fishermen it will as a result increase operator profits. For this to act as an incentive to operators to make such changes, however, it is also necessary that operators attempt to maximise their financial surplus.

In many fisheries, operators trade off fishing income against leisure time. As income per unit of fishing time increases, they may prefer increased leisure time to additional

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[1]See Copes (1976, 80) and Evans (1977, 10)

income, and so decrease the time they spend fishing. Assuming each operator has his own fishing unit, a reduction in fishing time per operator reduces the rate of capital usage and hence increases the cost of achieving a given effort level. Here rent retention may reduce rather than increase efficiency.[1] The net effect of rent retention on operator efficiency can only be deduced with referrence to exploitation of a specific fish stock.

On equity grounds, allowing rents to be retained by fishermen is frequently supported because of concern for what are considered a poor and disadvantaged group. There is no doubt that the major argument advanced for the introduction of limited entry schemes in traditional open entry fisheries is their ability to improve the welfare of the fishing communities involved.

If assistance to fishermen is considered necessary on equity grounds, allowing them to retain resource rents has several advantages over the alternatives. Since the rent is generated by the fisherman himself, it does not have the stigma associated with an untied government handout and therefore leads to a superior feeling of well being or additional psychic income above the actual monetary value of the assistance. It also has

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[1]The issues involved are very similar to those considered in attempting to assess the effect of varying tax rates on work incentives, a familiar public finance question.

the advantage over direct subsidisation of particular aspects of the fishing operation of not providing an incentive to distort resource allocations in order to maximise private returns. For example a special tax allowance for capital expenditure on fishing equipment is likely to lead to excessive expenditure on such equipment in terms of social as opposed to private costs and benefits.

One should, however, also consider critically the equity of such assistance. Fishermen's earnings are a function of their alternative employment opportunitites, not the economic state of the fishery. If fishermen are poor it is not because the fishery is unprofitable but because there is little work available elsewhere for them. If it is unwise in terms of encouraging resource reallocations to attempt to compensate all groups whose services are in low demand, why single out fishermen for special consideration?

In addition, fishermen may not in fact, all be as badly off as they appear at first glance. In most fisheries, a broad spectrum of earnings prevails,[1] due to differences in operator efficiencies. The benefits of rent retention accrue to all participants regardless of their actual earnings. Fishermen's incomes also frequently include a large psychic component in addition to their monetary remuneration, hence use of the latter

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[1]See Copes (1972).

will deflate their true overall income levels.

Evans (1977, 10) argues that "Resource rents are earned in other industries and seldcm are public attempts made to effect its disposition". He cites the example of an agriculturalist with rich land close to an urban market. The exceptions, however, for example royalty payments made for the right to exploit mineral and forestry resources on public lands, appear to be in situations which closely parallel the position in a limited entry fishery. Whilst the issue of whether a particular property should be considered as part of the public or private domain cannot be unambiguously resolved, fisheries would almost certainly appear to be towards the public end of the spectrum.

Note that the equity arguments advanced in support of rent retention by fishermen lose much of their force when the size of the fishing enterprise is such that participants are companies rather than owner-operators since the benefits then largely accrue to individuals unassociated with the actual fishing operations. In addition, the higher the resource rents generated by each operator the more difficult it is to justify full retention of these rents by them in terms of their need for welfare assistance.

Evaluation of all the above efficiency and equity arguments involves complex value judgements and will not be attempted here. It would appear however that for the South Australian prawn fishery a strong case on both efficiency and equity grounds for removal of at least part of the resource rents from the actual operators can be made.

As discussed in Section C.IV, there is evidence of short periods of operation and hence inefficient capital usage by many vessels in Spencer Gulf and especially Gulf St. Vincent. This is probably primarily an attempt by operators to lower profitability and so reduce the pressure for and hence likelihood of further licences being issued or of some rents being extracted from them. But it is also contributed to by the very high incomes which can be achieved at relatively low effort levels. Lack of profit motive may also hamper the willingness of all operators to make correct use of the effort flexibility provided by the non-restriction of vessel operating hours. Removal of part of the available resource rent from operators should reinforce the profit motive and hence lead to resource rent increases via improved efficiency and exploitation flexibility.

Given the apparent very high average incomes of operators in all fleets, the case on equity grounds for complete rent retention by them would also appear to be very weak.

III. RENT CAPITALIZATION AND ACCESS RIGHT TRANSFERABILITY

The value to a particular entity of the right of access to a limited entry fishery will equal the discounted value of the flow of above-normal returns or economic rents which the entity could obtain by participating in that fishery. It follows that if such rights are transferable on the open market, the free-market price will equal the highest value placed on such rights by a non-holder.

The initial recipient of such rights is therefore able to capture all of the above-normal returns which the above non-holder associates with them by a market sale, the rents being capitalised in the transfer price. Assuming the purchaser is realistic in his estimates of the future rents, he will, net of the cost of obtaining the access right, earn only a normal level of profits. Tullock (1976) refers to this ability of initial recipients to capture all monopoly profits associated with the entry restriction as the transitional gains trap, since subsequent rights holders earn only normal profits.

On the other hand, if the access right is non-transferable, the holder will only be able to capture rents by actually participating in the fishery himself, and hence the rents he will gain are limited to those over the length of time he is an active fisherman.

Several arguments are advanced in support of making access rights or licences non-transferable. Firstly, it prevents initial holders of such rights from capturing all of the future rents available to participants. This allows rents to be spread among successive generations of operators via the regular reissuing of expired licences.[1] This is considered more equitable than complete capture of all rents by initial licence holders. In addition it avoids the social problems which may be associated with all subsequent generations of fishermen earning only normal returns.

Secondly, if licences are non-transferable, all participants are earning above-normal profits, hence removal of some economic surplus can be achieved[2] without operators suffering overall capital losses. For this reason, it is suggested by Evans (1977, 13-4) as a useful interim measure until management decides its long term rent allocation strategy.

Thirdly, if licences are non-transferable, management is able to adjust the level of exploitation of the fish stock to meet changing circumstances merely by altering the number of expired licences which are reissued.[3] If licences are transferable, no licences will be surrendered, since they have a

[1]See Copes (1976, 10).

[2]The methods by which such removal can be achieved are discussed in more detail below.

[3]See Copes (1978, 129-30).

positive market value. If a reduction in the number of licences is desirable because of excessive effort, it will therefore require re-purchase of existing licences from current holders. This procedure, usually refered to as a buy-back, has yet to be successfully implemented because of the numerous administrative and socio-political difficulties which it gives rise to. A non-transferable system, by allowing effort to be reduced, therefore is likely to result in a superior level of exploitation if the stock is initially over-exploited.

Fourthly, if the capital market is imperfect, inability to obtain the funds necessary to purchase a licence in a fishery where large rents are retained by individual operators may preclude some owner-operators from participation if licences are freely transferable. For both equity and efficiency reasons, this may be considered undesirable.[1]

Fifthly, unrealistic optimism by potential participants may result in excessive prices being paid for transferred access rights, leading to subsequent social problems in the fishery. This is probably more likely where the individual fishing unit is small and unsophisticated, as here potential purchasers may be less well informed as to the actual size of the available rents and also because the existence of psychic income in such situations increases their willingness to absorb low financial

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[1]See Copes (1976, 10-11).

returns.

Note that the above advantages rely on fishing being undertaken by owner-operators. Company owned and managed fishing enterprises have an indefinite life hence do not need to transfer their access right to obtain the full value of future rents, and will never be forced to involuntarily surrender their licences. There are few equity arguments favouring redistribution of wealth to such entities. They are also likely to be reasonably accurate in their assessment of the true value of a fishing licence because of a more professional approach to evaluation and concentration on financial rather than psychic returns.

It is likely, however, that costs per unit of effort will be adversely affected by the application of a non-transferable lifetime licence policy. Initial recipients of such licences will probably not be the most efficient operators available. However, as long as they earn some rents from their fishing operations, they will not voluntarily relinquish their fishing rights. Sinclair (1978, 1026) argues that this leads to high cost "grandfather" fishing operators who retard the adoption of new technology and the entry of new low-cost production units. This may significantly reduce the level of resource rents generated at a given level of fishing effort.

The overall effect on resource rents of a no-transfer policy will depend on the extent to which effort is past the optimum level and the possible variation in operator efficiencies. Obviously if effort is well past the desirable level then a no-transfer policy, by achieving reductions in effort, will probably increase the rent level even if it increases unit fishing costs.

Existing participants usually favour transferable licences strongly because they are then able to capture future resource rents. This is especially the case if a tradition of licence transferability has been established in the fishery since decisions have already been made based on the ability to capitalize future rents, even if actual capitalization has not yet been achieved.

When considering the desirability of employing a non-transferability rule for prawn trawling authorities in South Australia, it should be initially emphasised that:

1. Authorities have been effectively transferable at market prices since the inception of the limited entry scheme.

2. Forty three percent of the current authority holders purchased their licences on the open market.

As a result, it is certain that at least some rent capitalization has already occurred for a large number of licences. The extent of this capitalization, however, is difficult to estimate.

Given that profit expectations and hence transfer prices of licences are largely based on profit levels at the time of sale, it is likely that only sales since the dramatic price escalation of 1974-75 would have achieved anything like full capitalization of 1976 to 1978 rent levels.

In addition, given the extremely high prices which it is rumoured[1] have been paid for vessels with authorities attached, $200,000 to $350,000, there may be relatively few potential owner-operators in the market, leading to the possibility of purchasers being able to retain some economic surplus for themselves.

The Government has indicated for some time that it plans to take action to remove a substantial proportion of the rents currently retained by prawn operators. Recent purchasers have no doubt reduced expected gains accordingly in estimating the value of authorities and hence the prices they paid for them.

It is considered that because of the substantial amount of money involved, and therefore the realism of the associated financial analysis, that no purchaser would have paid more than a realistic anticipated value of the licence purchased.

In summary it is considered that up to the present time some rent capitalization has occurred for somewhat less than 50% of current authorities, but that only for approximately half of these has anything approaching full capitalization been achieved. Even for recent sales, complete capitalizatin of all

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[1]Exact figures are unknown because of the uncertainty of the value of the under-the-table payment for the licence itself.

economic rents associated with a prawn trawling authority is probably unlikely.

The situation is in fact similar to that discussed by Evans (1977) in his analysis of the Shark Bay prawn fishery in Western Australia, the major policy issues being

1. Whether or not to continue to allow market trading of licences.

2. Whether or not to remove some (cr all) of the rents from participants.

3. Whether or not to differentiate between lcw cost operators (original licence recipients) and high cost operators (later entrants) in any rent removal procedure.

Each of the above issues, since they involve the evaluation of both equity and efficiency considerations, must eventually be resolved by the proces of political response. The following factors are, however, clearly relevant.

1. The State Government has permitted licence transfers to occur knowing that they were being accompanied by rent capitalization. Although, according to the regulations, prices paid on transfer of authorised vessels were meant to exclude any component for licence value, this has been ignored by routinely re-issuing discontinued licences to the purchasers of such vessels

regardless of the transfer price.[1]

2. Up to this time, full rent capitalization has occurred for very few licences.

3. The feasibility of a licencing scheme is considerably enhanced if it is acceptable to those most closely involved, namely current licence holders. They are likely to favour full rent retention and licence transferability.

4. Rent capitalization can occur only to the extent that rent are left in the hands of licence holders. The lower the degree of retention the lower the potential for capitalization.

5. The size of resource rents in the fishery is very high, hence the value of a licence if full capitalization occurs is very large.

6. There is little need at present to reduce the number of participants in any region of the fishery.

7. Most fishing units, although they are not company controlled, are reasonably sophisticated entities. They consist of a skipper, two or more crew and a vessel worth between $100,000 and $300,000. They are certainly not single man operations.

As writers such as Barlett (1973) and Buchanan and Tullock (1972) have demonstrated, government decisions are substantially influenced by the relative pressures applied by the affected groups. Whilst the size of the rent is largely independent of

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[1]See Section B. II.

its distribution, the potential rents for individuals within the two rival groups are likely to be far from equal. Individuals in the general community are probably not even aware of their extremely small shares of the possible gains from government rent collection and even if they were, because of the high cost of the organization necessary to bring effective pressure to bear, are unlikely to even attempt to sway the allocation in their favour. Each fisherman on the other hand, is very aware of his large individual potential gains and, because of their small number and common interests, as a group they face much smaller costs in collectively lobbying for their own interests.[1] They are therefore likely to push hard for the adoption of systems similar to those currently being applied. Given that all public intervention is at least to some extent politically motivated, some benefit to the regulated group is probably inevitable.

It is this author's opinion, that the most feasible overall strategy is to allow licences to be openly traded but at the same to time take immediate measures to remove a substantial part of economic surpluses from all operators. Special consideration of recent purchasers is not warranted at the present time. This would ensure that licences are held by the most efficient operators, avoid full capitalization of rents, allow the public to share in the fruits of the regulatory policy

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[1]The existence of fishermens' associations greatly facilitates such collective action.

and give some benefits to current participants.

Since current effort levels are not excessive, there is no significant welfare loss from the increased difficulty in achieving effort reductions. The moderate financial sophistication of the participants should make over-capitalization of rents unlikely.

IV. REMOVAL OF RESOURCE RENTS

It is desirable that the method used to remove resource rents from participants be equitable in that larger payments are made by those earning larger rents. This suggests that the payment be either in the form of an effort based fee or a tax or royalty on catch, and that separate scales of charges be calculated for each fish stock, where the stocks yield different rents per unit of effort.

Given that operators already pay a nominal fee per vessel year, a rough measure of fishing effort, it would be administratively simple to increase such fees to the levels at which the desired amount of rent is captured by the Government. It would probably be worthwhile to scale the charges by taking into account vessel length and BHP so as to provide an even better measure of potential rent levels for individual licences. The fishing power calculation results in Section D.IV could be used for this purpose.

It has also been argued[1] that measurement of the catch of each operator could be achieved with a minimal amount of difficulty. A tax or royalty based on actual yearly catches is therefore feasible.

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[1]See Section F.I.

As discussed by Copes (1975, 149-56), ideally the rent collection system should:

1. Be flexible, with the level of rent collected from a region adjusting with the overall rent level.

2. Be known in advance so that operators can incorporate it in their decision-making process.

As outlined earlier, prawn yields and hence total revenues from each stock are extremely variable, and resource rents, being a residual after subtraction of capture costs, exhibit even greater variability. For example a 10% increase in total revenue at a given effort level may increase rents from a region by perhaps 50%. In general, the profitability of a region also reflects the profitability of operators within that region, hence the latter also experience large variations in income.

The major disadvantage of a collection system based on licence fees set before each fishing season is its inflexibility. Because such a fee represents a largely fixed cost to the operator, it will result in even greater variability in his residual income.

A royalty on catch, however, adjusts with the catch level and hence operator profitability. This sensitivity of payments to actual operating results could be further increased by:

1. Making the royalty rate progressive, that is increasing it as the regional catch increases,

2. Relating the payment to revenue rather than catch levels,

hence also taking account of yearly price variations.

3. Indexing the rate structure to take account of changes in yearly cost levels per unit of effort.

Under such a system, the royalty payments made by operators would be related to the size of the rents captured and hence their ability to pay. Fluctuations in their incomes would be decreased rather than increased. Whilst Government receipts would be subject to large fluctuations, this is not a problem since it does not need to achieve a balanced budget on a yearly basis.

For these reasons it is considered that this latter type of system is the one which should be implemented in South Australia. Based on the very rough relative rent estimates made in Section E.IV, a hypothetical royalty rate scale for each region, based on total yearly regional revenue, is shown in Table XIV.

The royalty rate applied to the total receipts of each operator in a given region depends on the total value of the catch in that region. For example if the total revenue of all operators in Spencer Gulf is between \$5.5 m. and \$6.5 m., the royalty rate would be 2.5%, so an operator taking a catch worth \$200,000 would make a royalty payment of \$5,000.

To give some idea of the size of operator payments which would be made if the above scale were implemented, the average payments per operator in each fleet in the years 1975-76 to

TABLE XIV

HYPOTHETICAL ROYALTY RATE SCALES FOR EACH REGION AT 1977-78 COST AND PRICE LEVELS

West Coast		Spencer Gulf		Gulf St. Vincent		Investigator St.	
TR[1]	Royalty Rate (%)	TR	Royalty Rate (%)	TR	Royalty Rate (%)	TR	Royalty Rate (%)
all levels	0	0-5.5	0	0-1.2	0	0-.4	0
		5.5-6.5	2.5	1.2-1.4	2.5	.4-.5	2.5
		6.5-7.5	5	1.4-1.6	5	.5-.6	5
		7.5-8.5	7.5	1.6-1.8	7.5	.6-.7	7.5
		over 8.5	10.0	over 1.8	10.0	over .7	10.0

[1] TR is the total revenue for the region for the year.

1977-78 would have been as shown in Table XV.

In the absence of accurate data on cost levels in the industry, this scale could be indexed by a generally accepted cost index. The gross domestic product deflator would seem to be suitable for this purpose.

In a very sophisticated royalty scheme, the rates could also be varied during the year to match the rents associated with catches taken during different parts of the season. For example the rate could be reduced for catches taken late in the year when catch rates and rents are lowest to encourage operators to mop up the residual stock. This may induce operators to disguise the time of taking of their catch, however. It would also require detailed knowledge of the within-year changes in rent per unit of catch, and this is not currently available. For these reasons, this degree of sophistication is not feasible at this time.

A final comment is probably warranted concerning the constitutionality of a State Government levying a charge based on operator revenue. In general, State Governments in Australia are not permitted to levy sales or income taxes. There is therefore some doubt as to whether the above scheme is legal. This issue has already been raised by Copes (1975, 151) when he suggested a similar scheme for the Gulf of Carpentaria prawn fishery. Whilst this issue would have to be clarified before the scheme was implemented, it is considered that it should not

TABLE XV

AVERAGE ROYALTY PAYMENTS WHICH WOULD HAVE BEEN MADE UNDER THE HYPOTHETICAL ROYALTY RATE STRUCTURE BY OPERATORS IN EACH FLEET IN THE YEARS 1975-76 TO 1977-78

	Year	TR ($'m)	Royalty rate (%)	Total Royalty ($)	Royalty per Operator ($)
West Coast-Spencer Gulf[1]	1975-76	5.68	2.5	142,000	3,600
	1976-77	6.72	5.0	336,000	8,000
	1977-78	4.77	0	0	0
Gulf St. Vincent	1975-76	1.74	7.5	131,000	10,800
	1976-77	2.19	10.0	219,000	15,600
	1977-78	1.52	5.0	76,000	5,400
Investigator Strait	1975-76	.48	2.5	12,000	2,400
	1976-77	.55	5.0	27,500	5,500
	1977-78	.64	7.5	48,000	9,600

[1] For convenience, in calculating the royalty rate it was assumed all of the catch was taken in Spencer Gulf. This leads to a slight over-estimate of royalty payments for operators fishing in both regions.

present a major problem. One form of arrangement which could be used is to relate the current licence fee to the previous year's revenue, a system which has already been shown to be constitutionally valid.

V. ALLOCATION OF ACCESS RIGHTS

At the present time, it would appear that no adjustment in the number of operators in any fleet is required. Although current effort in Gulf St. Vincent is almost certainly below the optimum level at present, this will probably no longer be the case after all vessels adopt double rig and the two most recent licence recipients commence full time operations.

The question of how the number of operators in each region can be adjusted therefore has considerably less relevance than usual. It is an issue which should not, however, be completely ignored.

At present, as discussed in Section B.II, new licence holders are chosen at random from all suitably qualified applicants. Whilst having the advantage of not discriminating among such applicants, this system has the disadvantage of not necessarily resulting in the most efficient applicants receiving licences. In addition, if licences are transferable, it leads to the initial recipients being able to capture all future rents associated with them.

If all licences are transferable anyway, it may be preferable for the government to offer new licences for sale in the open market. This would lead to all rents being captured for the general public and guarantee that the licences would be gained by the most efficient non-holders, hence maximising the rent generated in the fishery.

In a similar manner, if it were considered that effort should be reduced, the government could purchase and retire one or more of the licences already on issue. Such re-purchases could be financed out of fees previously collected from partipants.

The other important aspect of current licence allocations is that processing companies are precluded from holding prawn trawling authorities. Where licences are non-transferable and there is a desire to distribute rents to successive generations of fishermen, the reasons for this rule are clear. Is its retention justified in a transferable licence scheme?

On efficiency grounds, it is considered that there are no significant economies of scale which could be reaped by processing companies by operating fleets of prawn trawlers. In fact it is likely that individual owner-operators will be more efficient because they have a maximum incentive to achieve the best operating results from the vessels of which they have direct charge.

Processors argue that if they were granted access rights then they would be able to achieve greater security of supply and so be less vulnerable to any monopolistic practices of other processors. This is undoubtedly true, but it would require processors to control the bulk of the catching capacity of the fleet.

In this latter situation, however, the unattached operators, who are undoubtedly weaker than processors in terms of market power The maintenance of the present owner-operator policy is likely to lead to a higher degree of competition in the market, a generally desirable situation if monopolistic manipulation of it by processors is to be avoided.

G. CONCLUSIONS

The most significant feature of the prawn fishery of South Australian is that stocks are capable of yielding extremely high levels of resource rents without large adjustment of current levels of exploitation in most cases. The major consideration is how to maintain this very favourable situation and achieve an equitable and acceptable distribution of the resultant benefits among current and future fishermen and the rest of society.

The existing management scheme, being based on separate regulation of each stock, is able to take into account the different characteristics of the fishing operation and stock in each region, an extremely important property of rational resource use.

Major conclusions with respect to the manner of exploitation of individual stocks are:

1. Access to the stocks should continue to be controlled by means of vessel licences. The number of such licences should be held at current levels.
2. The restrictions currently in force concerning the allowable characteristics of such vessels should be maintained, with the exception of the single rig requirement in Gulf St. Vincent, which should be discontinued.
3. The practice of allowing vessels to interchange freely between Spencer Gulf and the West Coast should be discontinued.

Instead, access should be restricted to a very small number of full-time operators and a few Spencer Gulf operators on a part-time basis.

4. A system of intermittent total closures should be implemented in Spencer Gulf in order to reduce fishing pressure early in the season, increase the average size of prawns caught and hence increase the price received for the catch taken in this region.

With respect to disposition of access rights and the resource rents currently generated in the fishery, the following conclusions may be reached:

1. A strong case can be made for removal of a substantial part of the available resource rents generated in the fishery for the general community. Given the variability of the rent level between years, operator payments in a year should be in the form of a royalty based on their total year's revenue. The royalty rate should be derived from the application of a progressive rate schedule to the total revenue generated in the region to which the licence applies.

2. In order to ensure that licences are held by the most efficient operators, the practice of allowing transfers of authorised vessels at market prices should be officially sanctioned. The government should also adjust the number of licences for each region by open market purchase or sale as it considers necessary.

3. The practice of excluding processing companies from the

holdings of authorities should be continued in order to ensure fair competetion between processors and independent owner-operators.

H. BIBLIOGRAPHY

Anderson, L. G. 1976. "The Relationship Between Firm and Industry in Common Property Fisheries." Land Economics. Vol. 52 (1), pp. 179-91.

--------------. (ed.). 1977a. Economic Impacts of Extended Fisheries Jurisdictions. Michigan: Ann Arbor Science.

--------------. 1977b. The Economics of Fisheries Management. Baltimore and London: John Hopkins University Press.

--------------. 1978. "Factor Rents, Worker Satisfaction, and the Optimal Level of Fisheries Exploitation." Draft, University of Delaware.

Australia, Bureau of Statistics. 1977. Fisheries 1976-77, Ref. No. 10.8. Canberra.

Australia, Fisheries Division, Department of Primary Industry. 1974. Economic Survey of the South Australian Prawn Fishery. Fisheries Report No. 12. Canberra: Australian Government Publishing Service.

Bartlett, R. 1973. Economic Foundations of Political Power. London: Collier-Macmillan.

Beverton, R. J. H. and S. J. Holt. 1957. On the Dynamics of Exploited Fish Populations. Fisheries Investigations Series II, Vol. XIX. London: Her Majesty's Stationery Office.

Bradley, P.G. 1969. "Some Seasonal Models of the Fishing Industry." in A. D. Scott, (ed.), H. R. MacMillan Lectures in Fisheries, Economics of Fisheries Management: A Symposium. Vancouver: Institute of Animal Resource Ecology, U.B.C., pp. 133-46.

Buchanan, J. M. and G. Tulloch. 1962. The Calculus of Consent, Logical Foundations of Constitutional Democracy. Ann Arbor, University of Michigan Press.

Byrne, J. L. and J. R. Harding. 1976. The Fisheries of South Australia: Legislation, Management and Economic Structure. Fisheries Background Paper 1. Adelaide: South Australian Department of Agriculture and Fisheries.

Christie, F. T. 1973. Alternative Arrangements for Marine

Fisheries, An Overview. Paper 1, Program of International Studies of Fishery Arrangements. Washington D.C.: Resources For The Future.

--------------. 1977. "Limited Access Systems Under the Fishery Conservation and Management Act of 1976." in L. G. Anderson (ed.), *Economic Impact of Extended Fisheries Jurisdictions*. Michigan: Ann Arbor Science, pp. 141-56.

Clark, C. W. and G. R. Munro, 1975. "The Economics of Fishing and Modern Capital Theory: A Simplified Approach." *Journal of Environmental Economics and Management*. Vol. 2, pp. 92-106.

Copes, P. 1972. "Factor Rents, Sole Ownership and the Optimum Level of Fisheries Exploitation." *The Manchester School*, Vol. 40 (2), pp. 145-63.

--------. 1975. *Development Prospects for the Fishing Industry of the Northern Territory*. Darwin: Dept. of Northern Australia.

--------. 1976. *Review of South Australian Fisheries*. Fisheries Green Paper 1. Adelaide: South Australian Department of Agriculture and Fisheries.

--------. 1977. "The Law of the Sea and Management of Anadromous Fish Stocks." *Ocean Development and International Law Journal*, Vol. 4(3), pp. 233-59.

--------. 1978. *Resource Management for the Rock Lobster Fisheries of South Australia*. Adelaide: South Australian Department of Agriculture and Fisheries.

Crutchfield, J. A. 1956. "Common Property Resources and Factor Allocation." *Canadian Journal of Economics and Political Science*, Vol. 22 (3), pp. 292-300.

-----------------, and A. Zellner. 1962. *Economic Aspects of the Pacific Halibut Fishery*. Fishery Industrial Research I. Washington: U.S. Department of the Interior.

Evans, G. C. 1977. "*Distributional Aspects of Fishery Resource Management*." M.A. Essay, Simcn Fraser University.

Fox, W. W. 1970. "An Exponential Surplus-Yield Model for Optimising Exploited Fish Populations." *American Fisheries Society Transactions*, Vol. 99, pp. 80-88.

--------. 1975. "Fitting the Generalised Stock Production Model by Least-Squares and Equilibrium Approximation." *Fishery*

Bulletin, Vol. 73 (1), pp. 23-35.

Gordon, H. S. 1974. "The Economic Theory of a Common-Property Resource: The Fishery." Journal of Political Economy, Vol. 62, pp. 122-42.

Graham, M. 1939. "The Sigmoid Curve and the Over Fishing Problem." Rapports process verbal du conseil international pour l'exploitation de la mer, Vol. 110 (2), pp. 15-20.

Griffin, W. L., M. L. Cross and J. P. Nichols. 1977. Effort Measurement in the Heterogeneous Gulf of Mexico Shrimp Fleet. Technical Report 77-5. College Station, Texas: Texas Agricultural Experiment Station, Taxas A&M University.

-------------, R. D. Lacewell, and J. P. Nichols. 1776. "Optimum Effort and Rent Distribution in the Gulf of Mexico Shrimp Fishery." American Journal of Agricultural Economics, Vol. 58 (4), pp. 644-52.

Gulland, J. A. 1956. On the Fishing Effort in English Demersal Fisheries. Fishing Investigations, Series II, Vol. XX. London: Her Magesty's Stationery Office.

-------------. 1969. Manual of Methods for Fish Stock Assessment: Part 1. Fish Population Analysis. Rome: Food and Agriculture Organization of the United Nations.

-------------. 1974. The Management of Marine Fisheries. Seattle: University of Washington Press.

Hynd, J. S. 1975. "The Management of Marine Fisheries from the Viewpoint of a Fisheries Biologist," in Australian Fisheries Council, Northern Fisheries Research Committee, National Prawn Seminar. Canberra: Australian Government Publishing Service, pp. 246-51.

King, M. C. 1977. "Methods of Conserving Small Prawns." SAFIC, Vol. 2 (3), pp. 7-9.

----------. 1978. "The Biology of the Western King Prawn Penaeus Latisulcatus Kishinouye and Aspects of the Fishery in South Australia." M.Sc. Thesis, University of Adelaide.

Knake, B. O., J. F. Murdock and J. P. Cating. 1958. Double-rig Shrimp Trawling in the Gulf of Mexico. Fishery Leaflet 470. Washington: Bureau of Commercial Fisheries , U.S. Department of Interior.

Neal, R. A. 1975. "The Gulf of Mexico Research and Fishery on Penaeid Prawns." in Australian Fisheries Council, Northern Fisheries Research Committee, National Prawn Seminar. Canberra: Australian Government Publishing Service, pp. 2-8.

Olsen, A. M. 1975. "The South Australian Prawn Fishery." in Australian Fisheries Council, Northern Fisheries Research Committee, National Prawn Seminar. Canberra: Australian Government Publishing Service, pp. 234-39.

Pontecorvo, G., D. M. Johnston and M. Wilkinson. 1977. "Conditions for Effective Fisheries Management in the Northwest Atlantic." in L. G. Anderson (ed.), Economic Impacts of Extended Fisheries Jurisdictions. Michigan: Ann Arbor Science, pp. 51-104.

Rounsefell, G. A. 1974. Ecology, Utilization and Management of Marine Fisheries. St. Louis: C. V. Mosby.

Ricker, W. E. 1975. Computation and Interpretation of Biological Statistics of Fish Populations. Bulletin 191. Ottawa: Department of the Environment, Fisheries and Marine Service.

Robson, D. S. 1966. "Estimation of the Relative Fishing Power of Individual Ships." Research Bulletin of International Commission for Northwest Atlantic Fisheries. No. 3, pp. 6-25.

Ruello, J. V. 1975. 'Quality control in the Prawn Fishery: Part 1. Storage of Prawns in Refrigerated Sea-water." in Australian Fisheries Council, Northern Fisheries Research Committee, National Prawn Seminar. Canberra: Australian Government Publishing Service, pp. 192-200.

SAFIC. Nov. 1976, Aug. 1977, Nov. 1977, and Aug. 1978. Adelaide: Fisheries Division of the Dept. of Agriculture and Fisheries and the Australian Fishing Industry Council in South Australia.

Schaefer, M. B. 1954. "Some Aspects of the Dynamics of Population Important to the Management of the Commercial Marine Fisheries." Bulletin of Inter-American Tropical Tuna Commission, Vol. 1 (2), pp. 27-56.

-------------- and R. J. H. Beverton, 1963. "Fisheries Dynamics-Their Analysis and Interpretation," in M. N. Hill, (ed.), The Sea: Ideas and Observation on Progress in the Study of the Seas, Vol. 2. Interscience, New York, pp. 464-83.

Scott, A. 1955. "The Fishery: The Objectives of Sole Ownership," Journal of Political Economy, Vol. 63, pp. 116-24.

Sinclair, W. F. 1978. "Management Alternatives and Strategic Planning for Canada's Fisheries." Journal of Fisheries Research Board of Canada. Vol. 35, pp. 1017-30.

Sluczanowski, P. R. 1978. "The Fishing Power of South Australian Prawn Trawlers." South Australian Fisheries Internal Report. Adelaide: Fisheries Research Branch, Fisheries Division, South Australian Department of Agriculture and Fisheries.

Smith, V. L. 1969. "On Models of Commercial Fishing." Journal of Political Economy, Vol. 77, pp. 181-98.

Tullock, G. 1975. "The Transitional Gains Trap." Bell Journal of Economics. Vol. 6 (2), pp. 671-81.

Walker, R. H. 1975. "Australian Prawn Fisheries." in Australian Fisheries Council, Northern Fisheries Research Committee, National Prawn Seminar, Canberra: Australian Government Publishing Service, pp. 284-304.

Western Waters Prawn Boat Owners Association. 1975. Letter to the Minister of Fisheries.

---. 1978. Paper presented to meeting of prawn fishermen.

White, T. 1975. "Factors Effecting the Catchability of Panaeid Shrimp." in Australian Fisheries Council, Northern Fisheries Research Committee, National Prawn Seminar, Canberra, Australian Government Publishing Service, pp 115-37.

Zoeteweij, H. 1957. "Fishermen's Renumeration." in R. Turvey and J. Wiseman (eds.), The Economics of Fisheries. Rome: Food and Agriculture Organization of the United Nations, pp. 18-34.