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DEMERSAL FISH STOCKS OF THE GREAT AUSTRALIAN BIGHT AS ESTIMATED FROM THE RESULTS OF OPERATIONS OF F. V. "SOUTHERN ENDEAVOUR"

By G. L. KESTEVEN* and A. E. STARK†

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Summary

This report presents an analysis of data concerning the operations of the F.V. *Southern Endeavour* in the Great Australian Bight in 1960–61 with a view to assessing how the characteristics of the resources in the area affected the outcome of the operations, and to contributing to an appraisal of those resources. The data analysed from the ship's fishing log relate to the date, time, and place of each of 942 hauls, to the conditions under which each haul was made, and to the catch taken on each.

Detailed analysis is made of the operations with respect to the time spent at sea in steaming to and from grounds, fishing, clearing nets, and lying-to for weather. Distribution of hauls with respect to area, depth, time of year, time of day, and wind force is described. The operational pattern was exceedingly unbalanced, especially with respect to geographic distribution in each season; this inbalance had important consequences for the statistical analysis.

Analysis was made, by Yates's "method of fitting constants to multiway tables", of rates of catch of three main species and a miscellaneous species group. This analysis showed a fixed pattern of diurnal change in catch rate for all species; it also showed significant differences in catch rate as between seasons (all species), depth, and area (all species except Bight redfish), and generally significant interactions of area with depth and season, and of depth with season; for jackass fish a significant second order interaction of area, depth and season was shown.

The overall mean catch rates (in hundredweight per hour of trawling) were: Bight redfish, 1·34; flathead, 0·29; jackass fish, 1·09; miscellaneous species group, 1·25. Although catch rates differed from these values from place to place and time to time, the results indicate that the density of stocks on the grounds was for practical purposes relatively uniform, both in space and time.

The results of the operations of this vessel are compared with those of other vessels on the Bight grounds and of vessels on other grounds. These comparisons suggest that the Bight stocks have probably an order of natural productivity the same as that of the stocks of the Australian east coast.

The *Southern Endeavour*'s fishing rate is tentatively estimated (from estimates of swept area) to have been at about 3% of the stock per annum. The weight of fishable stock of each species on these grounds is estimated (only tentatively) indicating a total of all species of about 15,000 tons.

I. INTRODUCTION

The continental shelf in the Great Australian Bight is the greatest shelf area of the southern half of Australia and has long attracted the attention of fishermen and others because it seemed that such an area could be expected to support substantial

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fishing. The F.I.S. *Endeavour* showed in 1913 that the Bight shelf was inhabited by a wide range of species of demersal fish. The fishing results (catch per unit effort) of this vessel were of the same order as, although lower than, the results obtained by her on the shelf off the coast of southern New South Wales and of Victoria.

After the work of the F.I.S. *Endeavour*, various other attempts were made to learn more about the Bight grounds, and to establish a fishery, by the following vessels: *Simplon* 1914, *Penguin* 1920, *Bonthorpe* S.T. 1929–30, *Trusan* 1948, *Ben Dearg* S.T. 1949–52, *Commiles* S.T. 1949–51, and in 1933 by a trawler from New South Wales. The results of these efforts, including those of the F.I.S. *Endeavour* were discussed by Houston (1954) in a paper directed mainly to analysis of the results of the operations of *Ben Dearg* and *Commiles* and to comparison of these results with those of other vessels in the Bight and on the Australian east coast grounds. Houston drew attention to mechanical defects of the *Ben Dearg* and *Commiles* and after pointing out that the activities and results of these vessels resembled those of the initial trawl fishing on the east Australian coast, he expressed the view that "catches from the Great Australian Bight might be expected to improve similarly, as experience accumulated"; similarly, that is, to the improvement effected on the east coast, which brought the catch to a level of 800,000 lb per vessel per year.

Houston's comparisons, which are discussed in Section V(*d*), and the view just quoted, undoubtedly constituted some of the basis for proposals, placed before the Commonwealth Government in 1957, for a substantive commercial fishing trial of these grounds. As a result of these proposals the F. V. *Southern Endeavour* was acquired and brought to Australia in 1959. The vessel, built in 1952, had previously operated from Great Britain under the name *Princess Elizabeth*. The principal characteristics of this vessel are given in Table 24. The vessel operated from April 13, 1960 to November 17, 1961, in which time she made 30 effective cruises. These operations were financially unsuccessful and the vessel was sold.*

The financial outcome of any fishing enterprise is determined of course by many things apart from the resource; these other things include vessel, crew, management, conditions on the grounds, and the arrangements for disposal of the catch. In assessing the results of some operations on a virgin ground, with a view to estimating the prospects of developing a fishery on them, a distinction ought to be made between the role of the resource and that of the fishing unit. This paper presents an analysis of catch and effort data from the *Southern Endeavour* operations, with the objective of assessing how the characteristics of resources in the Great Australian Bight affected the outcome of the *Southern Endeavour* operations.

Since the *Southern Endeavour* was acquired with the express intention of using it as a commercial fishing vessel, her captains were instructed to find and exploit concentrations of fish of commercial value. Decisions on these matters were left entirely with the captains with the exception that before cruise 11 the captain was directed to follow a fishing plan, formulated by CSIRO in consultation with him, which would distribute the effort more evenly over all the grounds being tried. This was the only attempt to impose any statistical form on the patterns of operations and,

* A report has been made on the operations of the company that managed the *Southern Endeavour*; see Department of Primary Industry (1966).

since the instruction was rescinded during cruise 15, had little effect on the character of the operations. As discussed in Section IV(*b*), the realized pattern had considerable unevenness in distribution of effort with respect to parts of the grounds and to factors which could have influenced the fishing results. The present paper is therefore to be seen as a report of an analysis of data from fishing operations of a strictly commercial nature: it is not an account of a planned experiment. CSIRO was invited to observe the operations and to make the present analysis.

The CSIRO officer* in charge of work in connection with these operations was able to make two trips on the vessel in 1960, in the course of which he made some biological examination of catches. A technical assistant also made two cruises. However, arrangements could not be made to provide on the *Southern Endeavour* accommodation suitable for scientific staff to carry out systematic work at sea, and therefore this effort had to be abandoned. Dr Kurth attempted to organize a programme of systematic sampling of the catch as landed, but for various reasons this was ineffective. Dr. Kurth has published, with Mr. I. S. R. Munro, a semi-popular account of the species composition of the *Southern Endeavour*'s catches (Munro and Kurth 1960). In this paper the nomenclature of the species caught has been kept consistent with that account. The fish logged as "king snapper" by the captains is *Trachichthodes gerrardi* (Gunther) or Bight redfish and fish logged as "morwong" is *Nemadactylus macropterus* (Bloch & Schneider) or jackass fish. Dr. Kurth's assistant, Mr. V. C. Han, is publishing a series of papers on the jackass fish which include data obtained from examination of *Southern Endeavour* catches, and present the results of the strictly biological research part of the *Southern Endeavour* project. The present paper is essentially an analysis of the evidence to be found in the *Southern Endeavour* records as to the nature of the resources on the Bight grounds.

II. The Bight Grounds

Since there are no established fishing grounds in the Bight the work of the *Southern Endeavour,* which was essentially a prospecting operation, must be examined with regard to standard geographic coordinates and such depth soundings as the charts of this little-explored area present. The approximate position of some main bottom contours are shown in Figure 1.

The total area of the continental shelf in the bight, from 123°30′ to 134°30′E., bounded on the seaward side by the 200-fm contour, is approximately 54,000 square nautical miles. The areas estimated to lie at various depths, over the whole of the Bight, are shown in Table 1. Most of the *Southern Endeavour*'s fishing took place, however, in 10 blocks (see Fig. 3) i.e. in about 7650 square nautical miles, which is about 14% of the total. Moreover, the operations were confined largely to ground between depths of 76–100 fm covering an area of about 2000 square nautical miles, which is less than 4% of the total area.

Information about the Bight and its fishable grounds is scanty. Some notes on the geology of the region, its benthos and zooplankton, its oceanography, and weather will appear in a later paper on the *Southern Endeavour* work. The authors of these notes were asked to give an indication of what was known, in their respective fields,

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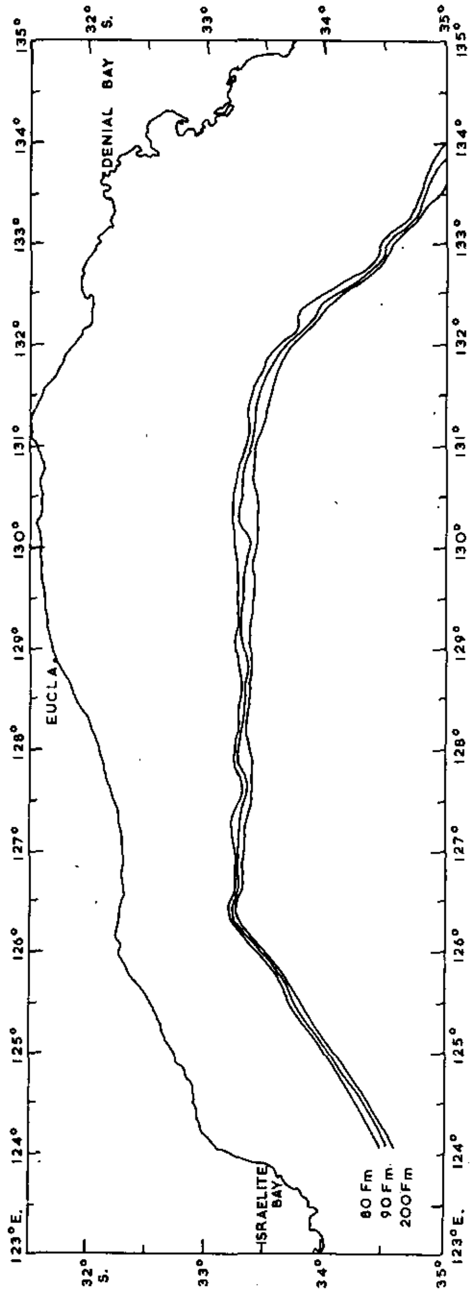

Fig. 1.—Great Australian Bight showing main contours.

of the Bight and, if possible, to make some comparison with the continental shelf off south-eastern Australia. The reason for asking for this comparison was that the south-eastern shelf is the only Australian area in which sustained bottom-net fishing takes place, and therefore the only fishing results with which the *Southern Endeavour*'s results can be compared, in a meaningful way, are those of the south-eastern fishery. Examination of differences, in a physical and biological sense, might elucidate differences of fishing results between the two areas.

TABLE 1

AREA OF THE CONTINENTAL SHELF OF THE GREAT AUSTRALIAN BIGHT AT VARIOUS DEPTHS, BETWEEN 123°30′E. AND 134°30′E.

Depth (fm)	Area (sq. nautical miles)	Percentage
0–25	7 560	14
26–50	32 508	60
51–75	10 206	19
76–100	1 984	4
101–200	1 795	3
Total	54 053	100

III. THE "SOUTHERN ENDEAVOUR" RECORDS

This analysis is based on three sets of records: (1) the log kept by the ship's captain, (2) the record kept, at the wharf, of the catches discharged from the vessel, and (3) various notes made by research staff and others of observations made by them, at sea, of the catch and of the gear and operations.

(*a*) *Captain's Fishing Log*

The captains kept the usual trawler log, ruled into columns, as follows:

Date
Time net shot
Time net hauled
Length of tow.—Hours and fractions of hours
Water depth.—Fathoms
Direction of tow
Catch.—King snapper, flathead, morwong; total baskets
Weather.—Chiefly wind direction and force
Remarks.—Note of fish (chiefly trash) rejected, of quantity of sponge and weed, and of nature of mishaps.

No record is extant (so far as we know) of the first three cruises. The records as to time spent on different operations (steaming, trawl down) are for the most part unambiguous and in making the analysis reported here these times were taken on their face value although in a few instances there is some doubt as to validity of the record.

The record of catch in the logs is the captain's tally of number of baskets each of 70-lb capacity; the relation between weights calculated from this and the record of catch as weighed on landing is discussed in Section III(*c*). Since the log had no column for "other species retained" we have had to assume that the difference between the total and the sum of the quantities of the three named species was the amount of "other species retained". In some cases an "other species" catch is shown in the remarks column, but the catch records in the "remarks" column are generally ambiguous. In some cases the record in the "remarks" column is of catch of species (such as leather jacket) taken and then thrown away; sometimes, however, the record shows "*x* baskets jackets, *y* baskets kept" whilst in others the record shows only "*x* baskets of jackets" and there is no indication of whether this is the total taken, the quantity rejected, or the quantity retained. In a few cases reference to the landed record gives a clue to the meaning of the captain's record in the "remarks" column.

TABLE 2

QUANTITY OF EACH OF THE CHIEF SPECIES LANDED BY THE "SOUTHERN ENDEAVOUR" FROM EACH CRUISE

All quantities stated as pounds weight

Cruise No.	Date	Bight Redfish	Flathead	Jackass Fish	Shark	Leather Jacket	Hake	Sea Carp	Mixed	Landed Catch
1	3–11. iii.60	15 025	420	3 287	420	280	70	295	1 093	20 890
2	15–26. iii.60	21 188	1 292	15 772	2 510	1 935	630	1 191	9 902	54 420
3	30 iii.– 9. iv.60	17 363	770	11 175	2 313	840	980	2 288	4 696	40 425
4	13–23. iv.60	10 543	420	9 030	1 260	1 326	210	1 890	6 545	31 224
5	24. iv–13. v.60	19 488	1 400	22 522	1 926	1 260	1 380	3 938	13 008	64 922
6	19–29. v.60	12 666	490	13 650	2 100	910	2 310	2 170	3 811	38 107
7	8–19. vi.60	9 143	6 790	24 628	448	2 089	2 925	1 680	14 401	62 104
8	8–22. vii.60	8 750	9 194	27 230	1 814	2 660	1 540	1 610	12 676	65 474
9	27. vii–12.viii.60	23 260	3 010	26 390	4 972	9 450	840	2 450	20 440	90 812
10	—	—	—	—	—	—	—	—	—	—
11	5–17. ix.60	13 270	1 960	12 714	3 181	4 340	2 310	1 470	7 770	47 015
12	22. ix– 7. x.60	12 514	3 570	32 556	5 536	4 171	770	1 470	6 838	67 425
13	13–25. x.60	16 690	2 800	17 924	2 256	5 514	6 456	1 553	2 855	56 048
14	31. x–11. xi.60	11 410	3 220	24 920	1 622	3 990	504	1 190	7 630	54 486
15	15–21. xi.60	3 010	350	4 690	595	350	70	560	2 170	11 795
16	23. xi– 9. xii.60	34 790	3 500	19 040	1 367	8 960	1 155	2 590	16 630	88 032
17	6–20. i.61	21 893	2 730	9 870	1 680	1 050	3 696	1 080	9 565	51 564
18	24. i– 5. ii.61	22 288	3 624	11 240	900	2 587	2 029	1 497	10 778	54 943
19	9–24. ii.61	20 111	3 174	26 432	1 200	1 259	1 470	490	12 271	66 407
20	4–17. iii.61	76 650	1 130	16 149	781	980	490	1 960	13 915	112 055
21	22. iii– 7. iv.61	63 255	1 850	24 096	595	910	560	2 100	18 853	112 219
22	12–28. iv.61	23 170	2 940	15 462	320	525	1 540	1 085	8 044	53 086
23	3–12. v.61	14 980	1 155	5 775	453	395	2 680	455	7 945	33 838
24	9–23. vi.61	8 500	5 040	10 780	1 515	1 050	1 190	1 287	15 350	44 712
25	29. vi–14. vii.61	9 360	17 260	12 500	4 290	1 570	1 990	1 540	13 199	61 709
26	20. vii– 5.viii.61	10 100	22 880	12 320	3 146	1 185	3 440	1 600	27 435	82 106
27	10–26.viii.61	12 360	5 320	12 954	6 565	1 610	980	1 525	30 564	71 878
28	31.viii–16. ix.61	6 215	3 780	10 330	8 640	1 470	640	560	30 168	61 803
29	22. ix– 6. x.61	9 280	3 520	8 628	5 010	1 610	770	720	32 259	61 797
30	11–26. x.61	25 200	4 795	11 854	10 542	3 500	1 639	2 730	31 700	91 960
31	2–17. xi.61	11 560	3 570	13 160	6 874	2 955	1 970	1 820	14 169	56 078
Total		564 032	121 954	467 078	84 831	70 731	47 234	46 794	406 680	1 809 334
Percentage of total		31·1	6·7	25·8	4·7	3·9	2·6	2·6	22·6	100

The matter of "other species" catch, trash, and fish rejected at sea, is discussed in Section V(*c*).

(*b*) *Record of Landed Catch*

On the wharf the catch was separated into eight species groups and the weight of each was recorded; the weight of landed catch of each group from each cruise is given in Table 2.

(*c*) *Discrepancies between Captain's Tally and Record of Landing*

The captain's estimate of species and total catch of each cruise is given in Table 3 with the percentage that his estimate is of the amount recorded at landing. The

TABLE 3

CATCHES BY "SOUTHERN ENDEAVOUR" ON EACH CRUISE

All quantities stated as pounds weight

Cruise No.	Bight Redfish		Flathead		Jackass Fish		Miscellaneous		Total	
	*a**	*b*†	*a*	*b*	*a*	*b*	*a*	*b*	*a*	*b*
4	13 230	126	735	175	12,390	137	5 635	50	31 920	102
5	23 590	121	1 715	123	22 470	100	19 075	89	66 850	103
6	13 040	95	210	43	13 650	100	10 850	96	36 750	96
7	9 520	104	5 600	83	28 700	117	14 560	68	58 380	94
8	10 360	118	8 820	96	28 910	106	18 340	90	66 430	102
9	22 540	97	3 010	100	29 050	110	40 250	106	94 850	104
11	12 740	96	1 400	71	13 230	104	49 490	260	76 860	164
12	15 960	128	4 690	131	40 180	123	20 720	110	81 550	121
13	21 980	132	2 730	98	17 710	99	18 620	100	61 040	109
14	13 860	122	3 010	94	26 320	106	11 550	77	54 740	101
15	4 200	140	420	120	4 410	94	1 820	49	10 850	92
16	35 560	102	3 150	90	21 350	112	19 740	64	79 800	91
17	23 030	105	3 360	123	17 080	173	25 340	148	68 810	133
18	21 770	97	3 430	95	10 640	95	10 080	57	45 920	84
19	18 130	90	3 710	117	19 740	75	12 390	74	53 970	81
20	74 620	97	1 820	161	13 650	85	24 640	136	114 730	102
21	54 180	86	2 660	144	19 740	82	10 150	44	86 730	77
22	16 030	69	2 660	91	13 510	87	6 510	57	38 710	73
23	12 880	86	1 540	133	6 650	115	8 400	70	29 470	87
24	10 290	121	4 130	82	11 480	107	14 910	73	40 810	91
25	11 480	123	15 330	89	13 650	109	14 070	62	54 530	88
26	10 080	100	20 720	91	13 650	111	21 630	59	66 080	81
27	13 650	110	5 290	101	14 980	116	22 610	55	56 630	79
28	8 890	143	5 110	135	15 820	153	22 190	54	52 010	84
29	9 870	106	4 760	135	13 650	158	27 020	67	55 300	90
30	23 730	94	5 040	105	14 070	119	22 960	46	65 800	72
31	11 130	96	4 690	131	13 230	101	16 800	61	45 850	82
Totals landed	515 340		119 840		469 910		490 280		1 595 370	

* Captain's tally of catch (in baskets each of 70 lb) converted to pounds weight.

† The percentage that the value in column (*a*) was of the corresponding record at landing (Table 2).

total of the estimates by the captains of the catches made on cruises 4–31 fell below the total recorded at the wharf by nearly 100,000 lb (6% of the recorded catch). The estimates for Bight redfish and flathead catches on these cruises approach very closely to the wharf record: +4864 lb in the case of redfish, and +168 lb in the case of flathead. The estimate of jackass fish catch exceeded the wharf record by 33,066 lb, whereas the estimate of miscellaneous species (of which, however, the captains kept no direct record) fell below the wharf record by 136,447 lb.

From these records it would seem that a reasonable explanation of the discrepance is as follows: fish of the three main species were fairly carefully sorted on the deck and loaded into baskets of which accurate tally was kept, but only rough estimate was made (perhaps by eye) of the remaining species, and in the majority of cases (22 out of 27) this was an underestimate. A few instances of discrepance for individual cruises require closer examination. For example, from cruise 11 the quantity of miscellaneous species landed was only about a third of the amount estimated by the captain; this however was almost certainly the occasion that a considerable quantity of fish was jettisoned on the way to port. For this cruise, then, the captain's estimate was a more accurate measure of the catch of miscellaneous species than was the "landed" record, and possibly the "overestimates" of the quantity of miscellaneous species taken on cruises 17 and 20 can be explained the same way and have the same status. This means that to the amount of miscellaneous species recorded as landed, 626,727 lb, some amount should be added for quantities jettisoned on these cruises. But, in addition there were the quantities of catch (of miscellaneous species) rejected on the grounds, referred to in the "remarks" column of the fishing log but not included in the captain's tallies of haul totals and, of course, not included in the "landed" record. We think from this evidence (see also Section V(*c*) (ii)) that the actual catch of miscellaneous species was 800,000 lb or more. This has to be kept in mind in considering the analysis of data on catch of this group.

Examination of records of individual cruises shows many quite large percentage differences between captain's tally and wharf record with respect to the three main species, the captain's tally being at times in excess of the wharf record by as much as 75%. Of course, the significance of a percentage discrepance depends on the absolute value of the amounts involved and for this reason the relation between the absolute amounts is presented, for each of the three main species, in Figure 2. This figure shows that although the captain's tally of Bight redfish and of flathead lies above the central line (of equality) more often than it lies below, all points lie within narrow limits; the scatter is slightly more for jackass fish. It seems that the captain's tally of the three main species was subject to various sources of error which operated at random and, in the long run of nearly 1000 hauls, cancelled out to result in totals very close to the true value. Error could have been caused by any of the following: uneven loading of baskets, misidentification of species, miscount of baskets as they were being loaded into the hold, or clerical errors in making the log entries. We of course are unable to measure or allow for any of these sources of error to judge whether they might have operated differentially with respect to the "factors" for which analysis of variance of catches has been made. We have had to assume that these sources of error operated randomly throughout the operations and that their effect has introduced no bias to our estimates of catch rates. Only analysis of data from further operations could test the validity of this assumption. We must emphasize that this assumption is not made with respect to the catch of miscellaneous species (which obviously was often underestimated and under-reported by the captains) nor with respect to the total, the tally of which carries the defect of the tally of miscellaneous species.

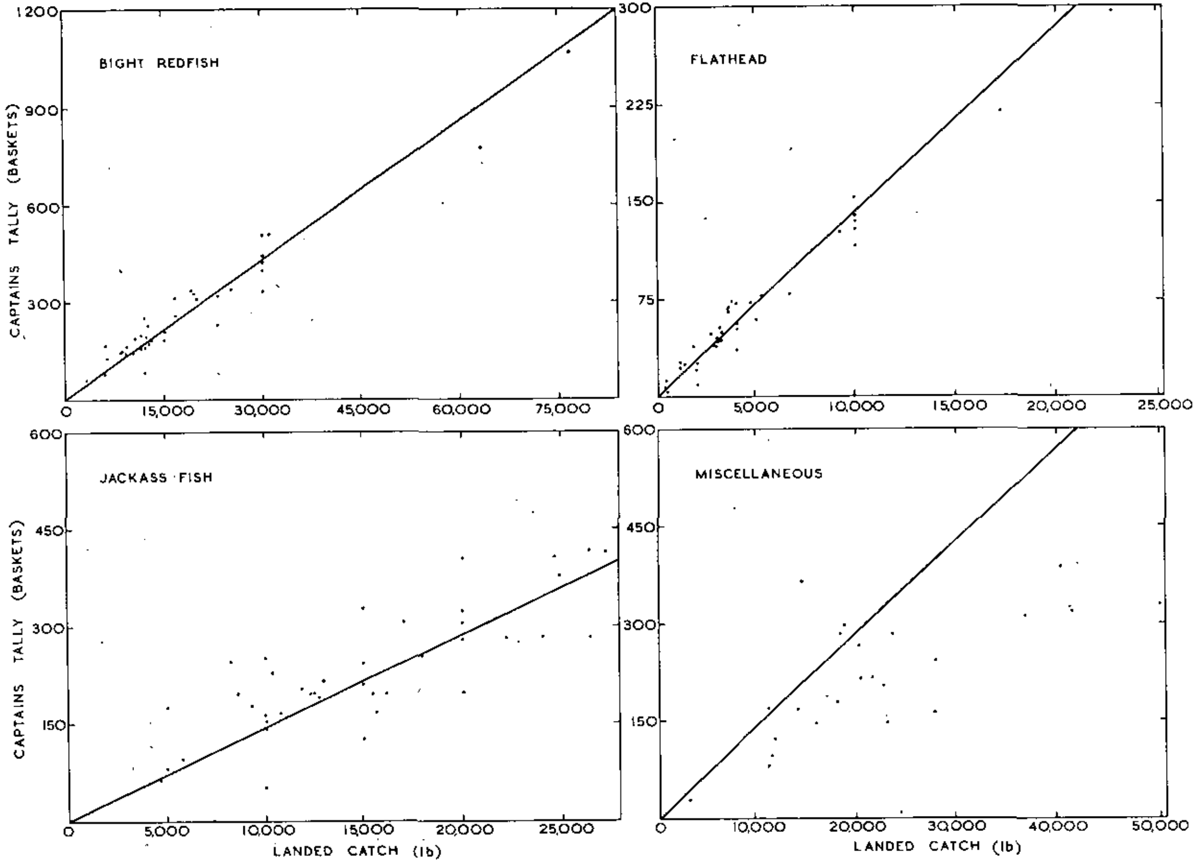

Fig. 2.—Relation between tally kept by captains on *Southern Endeavour* and landings from the vessel. The line drawn in the graph is of exact correspondence at 70 lb per basket.

(*d*) *Biological Data*

In the course of the work on the *Southern Endeavour* and in Adelaide samples of Bight redfish, flathead, and jackass fish were examined. The length and weight of fish in these samples were measured, sex and gonad condition were determined, and notes made on gut contents. The samples taken were too few to serve as a basis for a study of population structure but they add some detail to the picture of the composition of the catch and are reported on in Section VI(*c*).

IV. Fishing Operations of "Southern Endeavour"

(*a*) *General Considerations*

Over a period of approximately 19 months, the *Southern Endeavour* made 31 cruises, but one of these (No. 10) was abortive because of engine breakdown. In the course of these cruises, 1040 hauls were made; the number for each cruise is shown in Table 4. Of these hauls 77 were unsuccessful because of torn net and similar troubles. In the analysis reported in Section V, 14 hauls were not included because they were made in blocks only rarely fished and of the remainder 7 were excluded because their duration was less than $2\frac{1}{2}$ hr.

The character of the results from these operations was very greatly influenced by the determination that they should be conducted as closely as possible as commercial fishing. A major feature of commercial fishing is the influence exercised by the captain's decisions, which tend to be highly individualistic; in the present case various features of the data suggest that significant differences of this kind were introduced by the change of captains at the end of cruise 16. Differences are apparent in choice of area to be fished, in practices with regard to retention and rejection from catches of miscellaneous species, and may have been present with respect to hour-to-hour and day-to-day tactics. In cruises 4–19 only 4% of the hauls were made in the eastern area; this set includes three cruises under the second captain and we assume that on these he followed his predecessor's lead. However in the subsequent cruises only 3% of the hauls were made in the western area. The consequence of this difference is very considerable to the analysis, as discussed later. The matter of retention of miscellaneous species is also discussed later, with respect to both the amounts caught and retained, and the inadequacies of record.

In addition to differences between the captains in respect of their operational practices there were differences in the gear used. In January 1961 there was a change from 5 to $3\frac{1}{2}$-in. mesh; this, as noted in Section VI(*c*), apparently made little difference to the size composition of the catch, but it could have had some effect on fishing power and thus have contributed to the very noticeable change in catch rate of the several species as between the second and third of the periods into which we have divided the operations. The information in the records is insufficient to permit definitive assessment of these matters; we can only draw attention to the possibility that they contributed to some of the features of the results of the *Southern Endeavour*'s operations.

The records of these operations can be examined in several aspects of which two are relevant, one more than the other, to the purposes of the present study.

TABLE 4

CRUISES MADE BY THE "SOUTHERN ENDEAVOUR" AND THE HAULS MADE AND BLOCKS FISHED ON EACH

Cruise No.	Date of First Haul	Date of Last Haul	Successful Hauls		Unsuccessful Hauls	Total	Blocks Fished
			Included in Analysis	Excluded from Analysis			
4	16. iv.60	20. iv.60	20		3	23	91, 02, 10
5	1. v.60	10. v.60	30	1*	4	35	90, 91, 01, 02, 10, 11
6	21. v.60	26. v.60	22		1	23	02, 10, 11, 20, 21, 30
7	11. vi.60	16. vi.60	21		1	22	11, 20, 21, 22
8	11. vii.60	20. vii.60	32		1	33	11, 20, 21, 30
9	31. vii.60	8.viii.60	29	10*	1	40	60, 61, 80, 81, 01, 02, 10, 11, 20
11	7. ix.60	15. ix.60	35		3	38	02, 70, 71, 10, 11, 20, 21, 30
12	25. ix.60	5. x.60	47	2†	—	49	01, 02, 10, 11, 20, 21, 30, 31, 51
13	15. x.60	23. x.60	34	1†	2	37	70, 71, 02, 10, 11, 20, 21, 30, 40, 41, 50
14	2. xi.60	9. xi.60	28	3*	3	34	00, 01, 02, 10, 11, 20, 21, 30, 31
15	17. xi.60	20. xi.60	6	2†	3	11	20, 21, 30, 31
16	25. xi.60	6. xii.60	57		—	57	02, 10, 11, 20, 21
17	8. i.61	17. i.61	39		2	41	17, 02, 10, 11, 20, 21, 30, 31
18	26. i.61	2. ii.61	26	1†	3	30	01, 02, 10, 11, 20, 21, 30
19	11. ii.61	21. ii.61	43		4	47	02, 10, 11, 20, 21, 30
20	6. iii.61	16. iii.61	40		1	41	40, 41, 50, 51
21	24. iii.61	4. iv.61	48		—	48	30, 31, 40, 41, 50
22	15. iv.61	26. iv.61	38		—	38	20, 21, 30, 31, 40, 41
23	5. v.61	10. v.61	24		—	24	40, 41, 50, 51
24	11. vi.61	20. vi.61	34	1†	6	41	10, 11, 20, 21, 30, 31, 40, 41, 50, 51
25	1. vii.61	12. vii.61	39		9	48	21, 30, 31, 40, 41, 51, 52
26	22. vii.61	2.viii.61	38		8	46	20, 21, 30, 31, 40, 41, 50
27	12.viii.61	24.viii.61	32		6	38	20, 21, 30, 31, 40, 41, 50
28	2. ix.61	13. ix.61	44		5	49	20, 21, 30, 31, 40, 41, 50, 51
29	24. ix.61	4. x.61	48		1	49	30, 31, 40, 41, 50
30	13. x.61	25. x.61	45		7	52	11, 20, 21, 30, 31, 40, 41
31	4. xi.61	14. xi.61	43		3	46	11, 20, 21, 30, 31, 40, 41, 50, 51
Totals			942	21	77	1040	

* Block code 00, 52, 60, 61, 80, 81, 90, 91.

† Duration less than 2½ hr.

First there is the matter of assessing the extent to which the catch results were influenced by the pattern of operations, i.e. by the distribution of operations in time and space and their relation with factors affecting the distribution and abundance of the resources. Second we must examine the matter of performance, *not* to assess the efficiency of conduct of these operations, but, if it should be possible to do so, to assess the likelihood that the annual total effort of each of a number of vessels working these grounds could be greater than that achieved by the *Southern Endeavour* and hence that the total catch per vessel could be greater. Such a conclusion would obviously have considerable bearing on estimates of the prospective profitability of operations on these grounds and of the number of vessels that could be gainfully engaged in fishing these grounds.

TABLE 5

TIME SPENT BY "SOUTHERN ENDEAVOUR" IN VARIOUS OPERATIONS, IN ABSOLUTE VALUES AND AS PERCENTAGES OF VARIOUS CATEGORIES OF TIME USE FOR 27 CRUISES (5–9, 11–31, INCLUSIVE)

	Time		Percentages					
	Hours	Cumulative Total Hours	T_t	T_f	T_g	T_a	${}_AT_I$	${}_BT$
Failed hauls	100·00		2·63	1·88	1·74	1·18	0·87	0·74
Effective hauls	3708·05		97·37	69·56	64·43	43·67	28·48	27·27
Total trawl down		3 808·05 = T_t	100·00					
Between hauls	1522·40			28·56	26·45	17·93	11·69	11·20
Fishing		5 330·45 = T_f		100·00				
Laid to	424·63				7·38	5·00	3·26	3·12
On grounds		5 755·08 = T_g			100·00			
Steaming	2735·29					32·22	21·01	20·12
Absent from port		8 490·37 = T_a				100·00		
In port	4528·21						34·78	33·30
Total		13 018·58 = ${}_AT_I$					100·00	
+ in port between 9 and 11	578·00							4·25
		13 596·58 = ${}_BT$						100·00
∴ Total in port	5106·21							37·62

(*b*) *Time Analysis*

(i) *Total Operating Time*

The breakdown of the total lapsed time, from April 13, 1960 to November 17, 1961 is summarized in Table 5; the detail of this breakdown, for each cruise, is given in Table 6.

Of the total time, 67% (about 245 days) was spent at sea in cruises whose average duration was 13 days 11 hr. This contrasts with the performance of the same vessel operating from Great Britain: she is reported to have been at sea as much as 330 days in the year, that is, about 90%. In part this percentage was low because of the breakdown on the abortive cruise 10, and in part it was due to the protracted turn-round which averaged 7·6 days in contrast with 2–3 days normal for such vessels in Great Britain.

Of the time at sea 33% was spent in steaming to and from the fishing grounds; the journey took approximately 109 hr on the average. Lengthening the duration of

TABLE 6

TIME SPENT ON EACH CRUISE BY "SOUTHERN ENDEAVOUR", AND THE MAJOR SUBDIVISIONS OF THIS TIME

Cruise No.	Leave Port		Return to Port		No. of Hauls*	Hours Absent T_a	Hours on Grounds T_g	Hours Fishing T_f	Hours Trawling T_t
	Date	Time	Date	Time					
1	1. iii.60	n.a.†	11. iii.60	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.
2	15. iii.60	n.a.	26. iii.60	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.
3	30. iii.60	n.a.	9. iv.60	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.
4	13. iv.60	n.a.	23. iv.60	n.a.	23	n.a.	101·75	97·32	67·00
5	29. iv.60	1100	13. v.60	0100	35	326·00	221·75	173·25	105·30
6	19. v.60	0800	29. v.60	1400	23	246·00	124·58	119·78	84·75
7	8. vi.60	1600	19. vi.60	1100	22	259·00	144·75	113·47	82·75
8	8. vii.60	1630	22. vii.60	1600	33	335·50	240·25	208·03	133·25
9	27. vii.60	0700	12.viii.60	0700	40	384·00	207·25	207·25	156·00
10	—	—	—	—	—	—	—	—	—
11	5. ix.60	1800	17. ix.60	1100	38	281·00	194·25	194·25	141·50
12	22. ix.60	1600	7. x.60	0900	49	353·00	248·00	248·00	171·75
13	13. x.60	0800	25. x.60	1600	37	296·00	201·25	201·25	135·00
14	31. x.60	2100	11. xi.60	2100	34	264·00	170·50	170·50	127·00
15	15. xi.60	0930	21. xi.60	1800	11	152·50	47·75	47·75	30·25
16	23. xi.60	1230	9. xii.60	0800	59‡	379·50	280·00	280·00	212·25
17	6. i.61	0600	20. i.61	0635	41	336·59	212·25	212·25	136·25
18	24. i.61	0801	5. ii.61	0655	30	286·90	179·50	160·72	109·00
19	9. ii.61	0600	24. ii.61	0825	47	362·42	246·00	246·00	178·50
20	4. iii.61	0604	17. iii.61	0532	41	311·47	259·00	232·15	148·00
21	22. iii.61	0800	7. iv.61	0800	48	384·00	268·00	261·32	190·25
22	12. iv.61	0700	28. iv.61	1600	41‡	393·00	270·00	216·80	161·00
23	3. v.61	0800	12. v.61	1600	26‡	224·00	124·00	124·00	96·50
24	9. vi.61	0800	23. vi.61	1122	41	339·36	242·50	222·10	158·75
25	29. vi.61	0800	14. vii.61	1122	48	363·36	265·00	250·60	187·75
26	20. vii.61	0800	5.viii.61	0909	46	385·15	288·00	238·30	173·50
27	10.viii.61	0800	26.viii.61	0541	38	381·68	281·00	193·08	146·25
28	31.viii.61	0800	16. ix.61	0725	49	383·41	270·00	256·48	189·00
29	22. ix.61	0800	6. x.61	1550	49	343·83	239·50	239·50	194·00
30	11. x.61	0800	26. x.61	0606	52	358·10	287·00	270·62	188·25
31	2. xi.61	0800	17. xi.61	0836	46	360·60	243·00	243·00	171·25
Total for trips 5–9, 11–31 inclusive (27 trips)						8490·37	5755·08	5330·45	3808·05

* Number of hauls included in T_t. † Not available

‡ Includes several failed hauls ignored in main statistical analysis.

each cruise (hence reducing the number of journeys to and from the grounds), increase in cruising speed or operating from a base nearer to the grounds or both would have reduced this percentage and left more time for fishing.

On 26 occasions on the grounds the vessel had to lie-to for weather and other reasons; the time lost on each occasion averaged 17·2 hr, and the total time lost for these reasons was 8% of the total time on the grounds. Whether a vessel of other design or size could operate with a lower proportion of time lost for lying-to is a matter for consideration.

TABLE 7

NUMBER OF HAULS OF EACH DURATION INTERVAL MADE BY "SOUTHERN ENDEAVOUR" IN THE COURSE OF EACH CRUISE

Cruise No.	Trawl Duration (hr)											Mean Duration	Percentage of Hauls of 4-hr Duration
	2½	2¾	3	3¼	3½	3¾	4	4¼	4½	4¾	5		
4		2	12	6								3·05	0·0
5	3	1	12	3	2		9					3·30	30·0
6			3	2	5	1	11					3·67	50·0
7			4	1	1	1	13	1				3·75	61·9
8			1		1		24	1	5			4·04	75·0
9	1		1		4	2	12		9			3·98	41·4
11			3	1	11	3	16		1			3·73	45·7
12	3	2	5	2	9	4	20	1	1			3·61	42·6
13			2	2	12	4	14					3·69	41·2
14			1		11	4	12					3·73	42·9
15	3		1		2							2·92	0·0
16	1	2	5	4	15	12	17	1				3·61	28·8
17	2	1	17	2	7	1	9					3·32	23·1
18		1	4		5	1	15					3·69	57·7
19			6	2	6		27		2			3·78	62·8
20	1		9	3	9		16	1	1			3·59	40·0
21			7	1	14		25				1	3·71	52·1
22			1		7	2	25		2		1	3·92	65·8
23	1		4	2		2	15					3·69	62·5
24				2	2	1	29					3·92	85·3
25				2	4	3	26	1	1	1	1	3·95	66·7
26			5	1	6	2	22	1			1	3·79	57·9
27			2	3	6	1	19				1	3·80	59·4
28			5		5		33				1	3·85	66·7
29			1		2		45					3·96	93·8
30	1		7		12	3	22					3·66	48·9
31			9	1	6	2	23		1		1	3·73	53·5
Totals	16	9	127	40	164	49	499	7	23	1	7	3·72	53·0

Of the true fishing time, i.e. time on grounds less time laid-to for weather, 29% was spent between hauls in clearing the net, with an average of 1·19 hr on each occasion.

(ii) *Haul Duration*

Hauls varied in duration from something less than 2½ hr to 5 hr. The number of hauls, made on each cruise, in ¼-hr class intervals is given in Table 7, with average duration for each cruise and percentage of hauls of each cruise in the 4-hr interval. The mean haul duration was 3·72 hr with standard deviation 0·44. The cruise means differ significantly because of differences in spread rather than of change from one modal value to another. These differences of spread are reflected in the percentage that the number of hauls of 4-hr duration on each cruise was of the total number of hauls for the cruise. Roughly, the mean duration tended to be less and the proportion of hauls at 4 hr to be smaller on the earlier than on the later cruises. It would seem that the two captains differed in their methods of operation: the hauls made on cruises up to and including number 16 were slightly shorter on the average than those on cruises 17–31 (3·65 as against 3·76 hr) and there were relatively fewer hauls of 4 hr (41%) in the earlier cruises than in the later (60%). However, the differences between sets of cruises are not statistically significant. Although the differences between the cruise means are significant, there is no discernible pattern or trend to the values, and we must assume that the extreme values resulted from special operational characteristics of the cruises on which they appeared. Finally, attention may be drawn to the fact that 71% of the failed hauls occurred in the last 15 cruises.

(iii) *Discussion*

A critical element of the performance of any fishing vessel is the success in being at sea for a large proportion of each year and in being engaged in fishing for a large proportion of the sea-time. As noted above, the *Southern Endeavour* spent only 67% of her time at sea and only 67% of her sea-time in fishing. Detailed discussion of the reasons for the low value of these proportions and of the ways in which they might have been increased, or could be increased by any other vessel fishing these resources, has no place in this paper. However, it must be clear that any fiscal appraisal of the *Southern Endeavour*'s operations must make proper allowance for the time element of her performance.

(*c*) *Categorization of Data*

Since the characteristics of these grounds are still not known, and the biology of the species inhabiting them also is unknown, more especially with respect to habitat preferences, migrations, and patterns of movements, the analysis of variance, which is the main part of the works reported here, had to be carried out giving, initially, equal importance to the different "variables" with regard to which data are recorded in the captain's logs. The variables are: area (geographic block), depth, time of day, time of year, and wind force.

(i) *Area*

Figure 3 shows the number of hauls made in each ½-deg block of the Bight visited by the *Southern Endeavour*. Only 23 out of the 74 blocks were visited, and the majority of the visited blocks are those in which the edge of the continental shelf lies. Moreover a very large proportion of the hauls was located in nine of the visited blocks. This very uneven distribution of the hauls makes it impossible to carry out an analysis with a locality classification by blocks and therefore we have divided the grounds arbitrarily into three areas unequal in size but with approximately equal

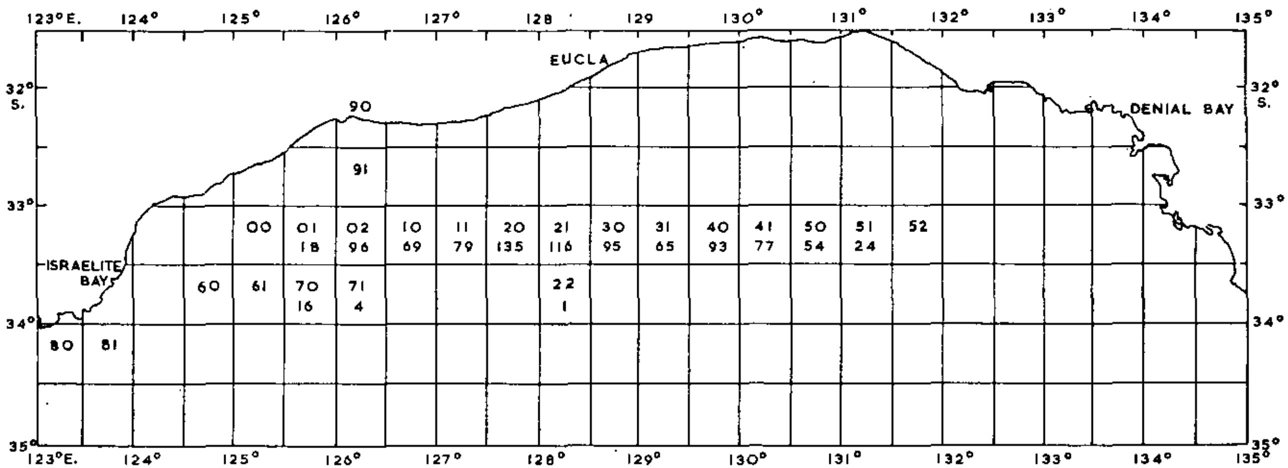

Fig. 3.—Half-degree blocks in which *Southern Endeavour* fished. The upper value is the block code number; the lower value, the number of hauls. The blocks to which the analysis in the text refers are listed in Table 9.

numbers of hauls. The following tabulation shows the spatial distribution of hauls made by *Southern Endeavour*.

Area	Blocks	Number of Hauls
Western	01, 02, 10, 11, 70, 71	282
Central	20, 21, 30	347
Eastern	31, 40, 41, 50, 51	313

(ii) *Depth*

Hauls were made in depths from 50 to 200 fm. Again there was considerable unevenness in distribution of hauls over these depths, and an arbitrary grouping had to

TABLE 8

DISTRIBUTION OF HAULS BY DEPTH

Depth	Approximate Area* (sq. nautical miles)	Number of Hauls	Haul Density (per 1000 sq. nautical miles)
Shallow, less than 81 fm (50–80 fm)	12 000	288	24·0
Medium (81–89 fm)	1 000	345	345·0
Deep, greater than 89 fm (90–200 fm)	2 000	309	154·5

* This is total bight area within these contours (see also Table 1 and Fig. 1).

TABLE 9

NUMBER OF HAULS MADE BY "SOUTHERN ENDEAVOUR" AT EACH OF THE DEPTHS RECORDED BY THE CAPTAINS

Depth (fm)	Hauls	Depth (fm)	Hauls	Depth (fm)	Hauls
50	2	83	98	100	30
60	2	84	1	105	15
65	5	85	158	110	20
68	1	86	1	115	5
70	30	87	9	120	3
73	2	88	77	125	3
75	60	90	120	130	3
77	3	93	11	140	1
78	29	95	84	150	3
79	1	96	1	180	1
80	153	97	3	200	2
82	1	98	4		

be made for the purposes of analysis. Depth as logged by the captain was from results of continuous echo-sounding and is given either to the nearest 5 fm or within the 5-fm range in which most of the haul was made (see Tables 8 and 9).*

* The areas given in Table 8 are for the east–west span of the Bight over which the *Southern Endeavour*'s operations extended and therefore differ from those of Table 1. The calculations of stock size, the method of which is discussed in Section VI (*a*) (i), refer to the areas of Table 8, although the total areas given in Table 1 are relevant to any examination of overall prospects.

(iii) *Time of Year*

The *Southern Endeavour* worked from April of one year to November of the next year and thus did not cover a full 2 years; of the first quarter of the calendar year and for the last month, there are data from only 1 year. For purposes of the analysis the full period has been divided arbitrarily into three periods, as in Table 10,

TABLE 10

TEMPORAL DISTRIBUTION OF HAULS MADE BY "SOUTHERN ENDEAVOUR"

Period	Cruise No.	Number of Hauls
I (April 1960–November 1960)	4–15	304
II (December 1960–June 1961)	16–23	315
III (July 1961–November 1961)	24–31	323

(iv) *Time of Day*

Since the *Southern Endeavour* worked on a round-the-clock basis, the hauls were made, as shown in the following tabulation, almost equally at different times of the day.

Diurnal Interval		Number of Hauls
Evening	(1800–2200)	157
Midnight	(2200–0200)	160
Dawn	(0200–0600)	162
Morning	(0600–1000)	165
Midday	(1000–1400)	163
Afternoon	(1400–1800)	135

(v) *Wind Force*

The number of hauls made in the presence of wind at each value of the Beaufort wind scale is shown in Table 11.

TABLE 11

NUMBER OF HAULS MADE BY "SOUTHERN ENDEAVOUR" IN PRESENCE OF WIND IN EACH INTERVAL OF BEAUFORT SCALE

Wind force	Hauls	
0	80	291* (0–2)
1	12	
2	199	
3	263	263
4	215	388 (4–8)
5	100	
6	46	
7	20	
8	7	

* Arbitrary grouping adopted for purpose of analysis.

TABLE 12

NUMBER OF HAULS IN EACH AREA × DEPTH × TIME OF DAY × PERIOD CELL

Time of Day	Period	Western Area			Central Area			Eastern Area		
		< 81 fm	81–89 fm	> 89 fm	< 89 fm	81–89 fm	> 89 fm	< 81 fm	81–89 fm	> 89 fm
1800–2200	I	9	10	12	11	7	12	3	1	1
	II	9	5	4	5	5	8	5	11	3
	III	—	1	—	6	5	14	10	6	4
2200–0200	I	11	13	8	3	10	5	1	1	—
	II	7	4	6	4	2	8	3	19	3
	III	1	2	—	5	9	3	11	12	9
0200–0600	I	6	10	14	1	8	11	—	1	1
	II	8	3	3	4	7	5	5	14	—
	III	—	2	—	10	10	10	10	11	8
0600–1000	I	6	11	12	4	9	5	1	1	1
	II	3	1	5	5	5	6	10	14	2
	III	—	1	—	9	9	14	11	13	7
1000–1400	I	7	12	14	1	8	4	—	—	3
	II	8	—	7	3	6	8	13	11	4
	III	1	1	1	7	4	9	15	6	10
1400–1800	I	5	8	14	1	11	6	—	—	1
	II	9	—	7	4	7	5	4	5	2
	III	1	—	—	5	6	8	17	7	2

(*d*) *Operational Pattern*

The arbitrary division, in the preceding section, of the five "variables" recorded by the captains establishes a theoretical number of 486 "cells"* in which it could have been possible to make hauls ($3 \times 3 \times 3 \times 6 \times 3$, i.e. three each for area, depth, time of year, and wind, and six for time of day). In 160 cells, however, no hauls were made

TABLE 13

NUMBER OF HAULS MADE BY "SOUTHERN ENDEAVOUR" IN EACH AREA–DEPTH CELL IN EACH PERIOD

	Western	Central	Eastern	Totals
Period I				
Shallow	44	11	5	60
Middle	64	53	3	120
Deep	74	43	7	124
Period Totals	182	107	15	304
Period II				
Shallow	44	25	40	109
Middle	13	32	75	120
Deep	32	40	14	86
Period Totals	89	97	129	315
Period III				
Shallow	3	42	74	119
Middle	7	43	55	105
Deep	1	58	40	99
Period Totals	11	143	169	323
Area Totals	282	347	313	942
Depth Totals				
Shallow	288			
Middle	345			
Deep	309			

and in the remaining 326 cells the number of hauls varied from one to nine. In order to have a set of cells with larger number of hauls in each (and for other reasons explained below) the "variable" wind was omitted and a frame of 162 cells was adopted as shown in Table 12 which reports the number of hauls made in each cell specified with respect to area, depth, period, and time of day. A summary of Table 12, with cells corresponding to those of Table 2, is given in Table 13.

None of the variables, by which the cells of Table 12 are specified, constitutes, of itself, a factor affecting fish distribution and abundance, or, with the exception of

* The term "cell" is used extensively in this paper to refer to a time and/or place and/or depth at which one or more hauls was made. It signifies a segment of space at a particular geographic location at a specified time.

wind force, affecting vessel performance, although for convenience they are referred to hereafter as factors in reporting the statistical analysis. The true determinative factors are undoubtedly things such as food, salinity, and temperature which may be assumed to have varied between and within the cells we have had to designate, arbitrarily, for the purpose of our analysis. In another period these factors might vary in some way other than that in which they varied during the *Southern Endeavour*'s work. Consequently, we must bear in mind that another vessel operating in any of these cells might meet conditions differing from those met by the *Southern Endeavour* and, that if it did, it could very well find quite different fish abundance. That is, the *Southern Endeavour*'s results may be representative of only some part of the range over which conditions in the Bight may vary. To a limited extent we can examine the possibility of limited representativeness, of this sense, by comparing the *Southern Endeavour*'s results with those of other vessels which operated in the Bight in other years. However, the value of such comparisons would depend to a large degree on the confidence we could place on the representativeness for its own period of each vessel's results. Therefore, in the first instance we must attempt to assess the grounds for confidence in the results of the *Southern Endeavour*. Since relative to the large cells with respect to which we have had to make our analysis, individual hauls were virtually instantaneous and covered only small areas, the catch from each haul could have been representative of only a small part of the total time–space matrix of its cell. Therefore we should, if possible, consider both whether the *Southern Endeavour* made a number of hauls in each cell sufficient, if properly distributed, to sample all the likely values of the matrix, and then whether in fact the hauls were properly distributed. At this stage we consider this matter essentially from the point of view of prior knowledge.

Information on the general location and extent of the grounds and on the composition of the stocks was made available at the beginning of the work. Fishing results of the *Endeavour*, *Ben Dearg*, and *Commiles* had given indications of the levels of catch rate that might be expected. However, there was no information on the patterns of distribution of each of the main species on the ground, nor, more especially, on the changes in these patterns that might take place diurnally, seasonally, and annually. Lacking this information, therefore, it could have been argued that a satisfactory account of fish abundance on the grounds could be obtained only from a sampling programme which sampled each depth zone (4) in each block (22) at least twice in each of six 4-hr intervals of the day, in each month: a total of 12,672 hauls. In a more practical view it could have been argued that some measure of homogeneity, and the existence of distributional gradients in space, and of cycles in time, would permit of estimates being made with a considerably smaller sampling scheme.

In the event, the results have shown a large measure of homogeneity of distribution and a constancy of diurnal pattern such that satisfactory results could have been obtained from a sampling programme much less extensive than the theoretical total of 12,672 hauls. The constancy of the diurnal pattern was such that, with normal round-the-clock working of a trawler and adjustment of results according to time of hauling, it would be unnecessary to include time-of-day as a factor in sample design, at once reducing the theoretical number from 12,672 to 2112.

Close examination of the individual fishing logs, and the statistical analysis reported below indicate that the gross lumping of data into three large areas, three unequal depth zones, and three unequal periods has meant that the real features of stock distribution have not been detected. A division of the area into some 15–20 sub-areas, with sampling in each of four depth zones, would seem to have been necessary; that is, some 60–80 space cells would have had to be sampled each month to obtain a satisfactory picture. This means that with replication at least 1440–1920 hauls per year would have been required. Since the *Southern Endeavour* accomplished only 660 hauls per year, it can be argued that even with systematic operations she could have accomplished only one-third to one-half of what was required in the limited part of the Bight to which the analysis here related. A lesser programme, say with bimonthly instead of monthly sampling of each cell (720–960 hauls), would have given less satisfactory results, but with improved management this could have been within the capacity of the *Southern Endeavour* and might indeed have been sufficient for practical purposes.

TABLE 14

NUMBER OF HAULS MADE BY "SOUTHERN ENDEAVOUR" IN EACH AREA AND AT EACH DEPTH

Depth	Western Area			Central Area			Eastern Area			All Areas		
	Hauls	Area (sq. miles)	Hauls per Sq. Mile	Hauls	Area (sq. miles)	Hauls per Sq. Mile	Hauls	Area (sq. miles)	Hauls per Sq. Mile	Hauls	Area (sq. miles)	Hauls per Sq. Mile
Shallow	91	2201	0·041	78	1210	0·064	119	1915	0·062	288	5326	0·054
Middle	84	173	0·486	128	101	1·267	133	252	0·528	345	526	0·656
Deep	107	269	0·398	141	281	0·502	61	652	0·094	309	1202	0·257

However, for the whole of the Bight, a much greater sampling programme would have been necessary. The practice in commercial fishing, of concentrating on high densities means that whilst the information obtained with respect to some areas is increased, the sampling area (of survey sense) per vessel per year is less than can be accomplished by a survey vessel operating on systematic plan. This effect has appeared in the *Southern Endeavour* work and has affected the results from it.

The distribution of hauls with respect to two main factors, area and depth is summarized in Table 14, with estimates of area in each cell, and of haul density.

V. CATCH AND FISHING RATES

(*a*) *Treatment of Data*

The record of catch of each species landed by *Southern Endeavour* from each cruise is given in Table 2 while Table 6 gives the record of effort expended, on each cruise, as hours absent, hours on ground, hours fishing, and hours trawling. From Table 6 a set of constants has been calculated for the conversion of size of catch of a

TABLE 15

"SOUTHERN ENDEAVOUR" CATCH PER UNIT EFFORT CONVERSION TABLE*

Cruise No.	$A \times 10^{-3}$ (cwt per 100 hr trawl down)	C (cwt per 100 hr fishing)	E (lb per hr on ground)	F (lb per day absent)
4	13·33	0·688A	0·737A	n.a.†
5	8·48	0·608A	0·532A	8·68A
6	10·54	0·708A	0·762A	9·26A
7	10·79	0·729A	0·640A	8·59A
8	6·70	0·641A	0·621A	10·68A
9	5·72	0·753A	0·843A	10·92A
10	—	—	—	—
11	6·30	0·728A	0·816A	13·54A
12	5·20	0·692A	0·776A	13·08A
13	6·61	0·671A	0·751A	12·26A
14	7·03	0·745A	0·834A	12·93A
15	2·95	0·634A	0·710A	5·33A
16	4·21	0·758A	0·758A	15·08A
17	6·55	0·642A	0·719A	10·88A
18	8·19	0·678A	0·680A	10·21A
19	5·00	0·726A	0·813A	13·24A
20	6·03	0·638A	0·640A	12·77A
21	4·69	0·728A	0·795A	13·32A
22	5·55	0·743A	0·668A	11·01A
23	9·25	0·778A	0·872A	11·58A
24	5·62	0·715A	0·733A	12·57A
25	4·76	0·749A	0·794A	13·89A
26	5·15	0·728A	0·675A	12·11A
27	6·11	0·757A	0·583A	10·30A
28	4·72	0·737A	0·784A	13·25A
29	4·46	0·810A	0·907A	15·17A
30	4·74	0·696A	0·735A	14·13A
31	5·21	0·705A	0·789A	12·77A
Total time	0·23	0·714A	0·741A	12·10A

* A = catch/$1 \cdot 12T_t$; B lb per hr trawl down = $1 \cdot 12A$; $C = A/(T_f/T_t)$; D lb per hr fishing = $1 \cdot 12C$; $E = A \times 1 \cdot 12/(T_g/T_t)$; $F = A \times 26 \cdot 88/(T_a/T_t)$.

† Not available.

species or of a total on each cruise to the various abundance measures (catch per unit effort) given in Table 15. These measures are as follows:

A catch, in hundredweight per 100 hr trawl down
B catch, in pounds per 1 hr trawl down
C catch, in hundredweight per 100 hr fishing
D catch, in pounds per 1 hr fishing
E catch, in pounds per 1 hr on grounds
F catch, in pounds per day absent

Table 16 gives the catch in hundredweight per hour trawl down for each species and for all species together on each cruise, calculated from the record of landings. The constants for derivation of measures *B–F* are to be applied to the values in Tables 16 and 20. A generalized table for these constants is given in Kesteven and Stark (1963).

Application of these constants gives estimates, of the above abundance measures, of the form

$$D^* = C/T \tag{1}$$

in which C = catch, T = total time, and D^* stands for abundance measure. For reasons discussed in Section IV(*a*) these estimates are not fully satisfactory. If T was

TABLE 16

"SOUTHERN ENDEAVOUR" LANDINGS PER HOUR TRAWL DOWN

All values in hundredweight

Cruise	No.	Bight Redfish	Flathead	Jackass Fish	Shark	Leather Jacket	Hake	Sea Carp	Mixed	Total	
April	4	1·40	0·06	1·20	0·17	0·18	0·03	0·25	0·87	4·16	2·66*
May	5	1·65	0·12	1·91	0·16	0·11	0·12	0·33	1·10	5·50	3·68
May	6	1·33	0·05	1·44	0·22	0·10	0·24	0·23	0·40	4·01	2·82
June	7	0·99	0·73	2·66	0·05	0·23	0·32	0·18	1·55	6·70	4·38
July	8	0·59	0·62	1·82	0·12	0·18	0·10	0·11	0·85	4·39	3·03
Aug.	9	1·33	0·17	1·51	0·28	0·54	0·05	0·14	1·17	5·20	3·01
Sept.	11	0·84	0·12	0·80	0·20	0·27	0·15	0·09	0·49	2·96	1·76
Sept.–Oct.	12	0·65	0·19	1·69	0·29	0·22	0·04	0·08	0·36	3·51	2·53
Oct.	13	1·10	0·19	1·19	0·15	0·36	0·43	0·10	0·19	3·71	2·48
Nov.	14	0·80	0·23	1·75	0·11	0·28	0·04	0·08	0·54	3·83	2·78
Nov.	15	0·89	0·10	1·38	0·18	0·10	0·02	0·17	0·64	3·48	2·37
Nov.–Dec.	16	1·46	0·15	0·80	0·06	0·38	0·05	0·11	0·70	3·70	2·41
Jan.	17	1·43	0·18	0·65	0·11	0·07	0·24	0·07	0·63	3·38	2·26
Jan.	18	1·83	0·30	0·92	0·07	0·21	0·17	0·12	0·88	4·50	3·05
Feb.	19	1·01	0·16	1·32	0·06	0·06	0·07	0·02	0·61	3·32	2·49
March	20	4·62	0·07	0·97	0·05	0·06	0·03	0·12	0·84	6·76	5·66
March–April	21	2·97	0·09	1·13	0·03	0·04	0·03	0·10	0·88	5·27	4·19
April	22	1·28	0·16	0·86	0·02	0·03	0·09	0·06	0·45	2·94	2·30
May	23	1·39	0·11	0·53	0·04	0·04	0·25	0·04	0·74	3·13	2·03
June	24	0·48	0·28	0·61	0·09	0·06	0·07	0·07	0·86	2·51	1·37
July	25	0·45	0·82	0·59	0·20	0·07	0·09	0·07	0·63	2·93	1·86
July	26	0·52	1·18	0·63	0·16	0·06	0·18	0·08	1·41	4·23	2·33
Aug.	27	0·75	0·32	0·79	0·40	0·10	0·09	0·09	1·86	4·39	1·86
Sept.	28	0·29	0·18	0·49	0·41	0·07	0·03	0·03	1·43	2·92	0·96
Sept.–Oct.	29	0·43	0·16	0·40	0·23	0·07	0·04	0·03	1·48	2·84	0·99
Oct.	30	1·20	0·23	0·56	0·50	0·17	0·08	0·13	1·50	4·36	1·99
Nov.	31	0·60	0·19	0·69	0·36	0·15	0·10	0·09	0·74	2·92	1·48
Averages		1·196	0·265	1·085	0·175	0·156	0·117	0·111	0·882	3·983	2·546
Gross†		1·197	0·280	1·024	0·187	0·156	0·107	0·101	0·917	3·971	2·458

* Last column shows total weight of Bight redfish, flathead, and jackass fish.

† The values of this line are calculated by dividing total catch over all cruises by total time trawl down.

the sum of a great number of operations randomly distributed over all the grounds and throughout the year, estimates in the form *A* would be unbiased and could be used for the purposes of discussing the abundance of the different species. But since the operations were most unevenly distributed these estimates are of only limited value. For this reason we turn to the captain's tally of catch since only in these is detailed information recorded of time, place, and circumstance of each haul. Whilst the variance of estimates of the form (1) for each cruise can be calculated for testing the significance of differences between these measures, the comparisons are uninformative because the only significant difference between the cruises, for comparisons, is in the dates on which they were conducted. In contrast, using the captain's tally, analysis can be made of data from individual hauls taking account of circumstantial characteristics which have some likelihood of being associated with determinative factors. The first step in this analysis was to identify the nature of the distribution of the catches. Examination of the variation of catches of each cell about the cell mean (for all cells with more than one haul) showed a roughly linear relation between mean and standard deviation. Accordingly a logarithmic transformation was made of the data, eliminating this dependence.

Next, an examination was made of the significance of between-cell variance in general. Table 17 shows that the between-cell variance was significantly greater than the within-cell variance, indicating that a more extensive analysis could be informative. The method then used, although differing in computational detail, is equivalent to the technique called the "method of fitting constants to multi-way tables" by Yates (1960). In the first instance the analysis was made, for each species, in a six-way

TABLE 17

ANALYSIS OF VARIANCE OF CATCH DATA (CAPTAIN'S TALLY) FROM "SOUTHERN ENDEAVOUR"

Source of Variation	Degrees of Freedom	Mean Square			
		Bight Redfish	Flathead	Jackass Fish	Miscellaneous
Between cells	325	0·2814***	0·0960***	0·1087***	0·2187***
Within cells	615	0·1125	0·518	0·0730	0·1072
Total	940†				

*** Significant at 0·1% level.

† One observation omitted through machine error.

classification of period, area, depth, time of day, haul duration, and wind force. The analysis gave six groups of main-effect constants and 15 groups of first-order interaction constants. The significance of each group of constants (for each species) was tested separately by comparing the goodness of fit of the model with all groups fitted, with its goodness of fit obtained with the omission of each group in turn. The outcome of these tests is given in Table 18.

This analysis showed wind force to have significant (1% level) association with catch rate only for the miscellaneous species group. Of the interactions of wind force with other factors, that with area was significant (1% level) for flathead, and that with time of day was significant (5% level) for the miscellaneous species group. In view of this relative low degree of significance (in contrast with other effects) this factor was dropped from the further stages of the analysis.

Duration of haul had significant effect, of various levels of significance, on catch. The catch of flathead and of the miscellaneous species group was positively and significantly associated with haul duration which accords with the assumption of

TABLE 18

RESULTS OF TESTS TO FIND ASSOCIATION BETWEEN CATCHES AND FACTORS

Group	Numerator Degrees of Freedom	F Value			
		Bight Redfish	Flathead	Jackass Fish	Miscellaneous
(a) Initial analysis including all factors and two-factor interactions					
Main Effects					
Area (*A*)	2	1·92	7·25***	6·70**	20·51***
Depth (*D*)	2	2·89	6·36**	5·71**	0·44
Wind force (*W*)	2	0·09	2·69	1·80	6·63**
Time of day (*T*)	5	25·87***	3·58**	2·02	3·00*
Period (*P*)	2	26·55***	9·09***	5·08**	9·03***
Duration (*H*)	2	2·19	4·78**	0·46	6·46**
Interactions					
$A\times D$	4	3·91**	2·22	0·96	0·42
$A\times W$	4	0·99	4·05**	1·92	1·53
$A\times T$	10	1·79	1·33	0·83	1·14
$A\times P$	4	12·21***	1·19	2·77*	4·41**
$A\times H$	4	0·91	1·99	2·23	1·48
$D\times W$	4	0·82	0·87	2·37	0·44
$D\times T$	10	0·36	1·09	0·96	0·46
$D\times P$	4	6·08***	7·32***	9·68***	1·33
$D\times H$	4	0·72	2·40*	2·48*	2·19
$W\times T$	10	1·41	0·80	0·95	2·21
$W\times P$	4	0·71	2·37	2·76	0·72
$W\times H$	4	0·35	1·39	1·94	1·24
$T\times P$	10	0·91	1·17	1·39	2·27*
$T\times H$	10	0·80	1·32	0·42	0·97
$P\times H$	4	2·46*	0·29	0·89	5·72***
(b) Selective analysis omitting wind force and interactions involving time of day					
Main Effects					
Area (*A*)	2	1·72	10·63***	9·13***	15·76***
Depth (*D*)	2	2·33	4·84**	3·33*	0·68
Period (*P*)	2	20·82***	14·62***	5·31**	24·45***
Time of day (*T*)	5	41·71***	5·39***	1·90	4·58***
Interactions					
$A\times D$	4	3·18*	3·00*	3·75**	0·43
$A\times P$	4	14·50***	1·33	5·56***	16·66***
$D\times P$	4	3·85**	3·79**	7·40***	1·75
$A\times D\times P$	8	—	—	2·29*	—

* Significant at 5% level; ** Significant at 1% level; *** Significant at 0·1% level.

proportionality normally made in this type of work. In the case of Bight redfish and of jackass fish, however, the association was non-significant and plots of the relation for these species showed a tendency for decrease in catch with increase in haul duration. However, for reasons dealt with in a later section, the analysis was then developed on the data converted to catch rates, thus eliminating duration of haul as a factor.

Further analysis was made in two stages. An analysis was made of catch rates, transformed logarithmically, with respect to the factors period, area, depth, and time of day. Next, all interactions involving time of day were omitted and a second-order interaction of period, area, and depth was introduced. This new interaction, being found significant only for jackass fish, was eliminated from a further analysis for the other species.

The results of this two-stage analysis are presented in Table 18(*b*). It will be seen that these results differ only in degree from those of Table 18(*a*); in no case does a main effect or interaction which was significant in Table 18(*a*) have no significance in Table 18(*b*). The dropping of factors therefore has not complicated this investigation of associations.

This analytical procedure serves two purposes. First it points to, and permits assessment of associations prevailing between catch rates and various factors which might have influenced the operation of the fishing gear and the abundance of the fish (taking "abundance" in a broad sense). Second it presents a basis for estimation of "true" mean catch rates for each of the several divisions of the Bight grounds in different seasons. The analysis in fact imposes a pattern on this estimation: namely, that the means should be calculated for area × depth × time of day cells in each period. Such estimates carry an implication that the stock was homogeneously distributed within each such cell, an implication to which we return in Section VI.

Although the analysis of variance has been carried out on arrays of catch rates, each rate calculated from the catch and duration of a single haul, a choice of procedure for estimation of mean rate presents a little difficulty. The problem can be seen as basically a matter of regression analysis in which the catch y_i is expressed as a function of duration x_i in an equation

$$\text{expected value}\,(y_i) = bx_i,$$

in which b is the constant of proportionality. The general expression for weighted estimates of b takes the form

$$b = \left(\sum_{i=1}^{n} w_i x_i y_i\right) \bigg/ \left(\sum_{i=1}^{n} w_i x_i^2\right). \tag{2}$$

Where w_i is inversely proportional to the variance of y_i the estimator is the best linear unbiased estimate. Three other estimators, special cases of (2) are:

$$b_1 = \Sigma xy / \Sigma x^2, \tag{3}$$

$$b_2 = \Sigma y / \Sigma x, \tag{4}$$

$$b_3 = \frac{1}{n} \Sigma y/x; \tag{5}$$

b_1 gives equal weight to each observation; b_2 gives weights inversely proportional to x; b_3 gives weights inversely proportional to x^2. The second of these, which is an

TABLE 19

CATCH RATES* AND STANDARD ERRORS, BY PERIOD, AREA, AND DEPTH

Values are means for the designated statistical cells

Period	Depth	Western Area	Central Area	Eastern Area	All Areas	Species
			Redfish			
I	Shallow	1·19(15)†	i.d.‡	i.d.	1·19	
	Middle	1·56(9)	0·80(14)	i.d.	1·18	
	Deep	1·55(11)	1·14(22)	i.d.	1·34	
	All depths	1·43	0·97	0·86§	1·20	
II	Shallow	2·02(11)	1·43(18)	1·76(17)	1·74	
	Middle	1·02	1·39(12)	3·11(14)	1·84	
	Deep	1·40(40)	1·22(14)	2·59	1·75	
	All depths	1·48	1·35	2·49	1·77	
III	Shallow	i.d.	0·81(10)	0·53(10)	0·67	
	Middle	i.d.	0·81(18)	0·53(13)	0·67	
	Deep	i.d.	0·72(14)	0·57(18)	0·64	
	All depths	1·02§	0·78	0·54	0·66	
Means		1·45	1·03	1·52		1·33
			Flathead			
I	Shallow	0·13(17)	i.d.	i.d.	0·13	
	Middle	0·21(19)	0·47(10)	i.d.	0·34	
	Deep	0·17(10)	0·27(12)	i.d.	0·22	
	All depths	0·17	0·37	0·11§	0·23	
II	Shallow	0·18(11)	0·20(12)	0·14(13)	0·17	
	Middle	0·13	0·24(14)	0·12(11)	0·16	
	Deep	0·32(31)	0·20(14)	0·13	0·22	
	All depths	0·21	0·21	0·13	0·18	
III	Shallow	i.d.	0·25(10)	0·25(11)	0·25	
	Middle	i.d.	0·40(16)	0·33(15)	0·36	
	Deep	i.d.	0·91(20)	0·59(25)	0·75	
	All depths	0·25§	0·52	0·39	0·45	
Means		0·19	0·37	0·26		0·29
			Jackass Fish			
I	Shallow	1·06(14)	i.d.	i.d.	1·06	
	Middle	1·77(10)	2·15(17)	i.d.	1·96	
	Deep	1·97(10)	2·09(14)	i.d.	2·03	
	All depths	1·60	2·12	0·95§	1·68	
II	Shallow	1·03(9)	0·82(9)	0·72(9)	0·86	
	Middle	1·06	1·12(12)	0·86(6)	1·01	
	Deep	1·09(10)	1·06(10)	0·81	0·99	
	All depths	1·06	1·00	0·80	0·95	

* † ‡ § For explanation of symbols see foot of Table 19, p. 31.

TABLE 19 (*Continued*)

Period	Depth	Western Area	Central Area	Eastern Area	All Areas	Species
			Jackass Fish (*Continued*)			
III	Shallow	i.d.	0·91(10)	0·68(4)	0·80	
	Middle	i.d.	0·68(6)	0·63(7)	0·66	
	Deep	i.d.	0·83(7)	0·67(9)	0·75	
	All depths	0·52 §	0·81	0·66	0·74	
Means		1·33	1·14	0·72		1·09
			Miscellaneous			
I	Shallow	1·61(19)†	i.d.	i.d.‡	1·61	
	Middle	1·63(9)	1·64(16)	i.d.	1·63	
	Deep	1·88(12)	1·73(27)	i.d.	1·80	
	All depths	1·71	1·68	0·68 §	1·89	
II	Shallow	0·86(9)	0·81(22)	0·49(23)	0·72	
	Middle	1·47	0·83(15)	0·31(19)	0·87	
	Deep	1·07(18)	1·16(22)	0·21	0·81	
	All depths	1·13	0·93	0·34	0·80	
III	Shallow	i.d.	1·16(10)	1·02(9)	1·09	
	Middle	i.d.	1·02(11)	1·02(10)	1·02	
	Deep	i.d.	1·20(7)	0·99(15)	1·10	
	All depths	1·08 §	1·13	1·01	1·07	
Means		1·42	1·36	0·68		1·25
			Total			
I	Shallow	3·99	i.d.	i.d.	3·99	
	Middle	5·17	5·06	i.d.	5·12	
	Deep	5·57	5·23	i.d.	5·40	
	All depths	4·91	5·14		4·85	
II	Shallow	4·09	3·26	3·11	3·49	
	Middle	3·69	3·58	4·40	3·89	
	Deep	3·88	3·64	3·73	3·76	
	All depths	3·89	3·49	3·75	3·71	
III	Shallow	i.d.	3·13	2·48	2·80	
	Middle	i.d.	2·91	2·51	2·71	
	Deep	i.d.	3·66	2·82	3·24	
	All depths		3·23	2·60	2·92	
Means		4·40	3·84	3·18		3·83

* In hundredweight per hour.

† Standard error as percent of mean shown in parentheses.

‡ Insufficient data.

§ Assumed value, not included in the calculation of higher-cell means.

unbiased estimator, has been used here for reasons of computational convenience, because it pools the results of hauls taken close together in time, and because it is a measure which appears frequently in literature.

Although time of day is shown in Table 18(*b*) to be a significant main effect on catch rate, for Bight redfish, flathead, and the miscellaneous group, its interactions are shown in Table 18(*a*) to be non-significant except for the miscellaneous species group, for which it interacted with season with 5% level of significance. The non-significance of the interactions indicates that the diurnal patterns of catch rate for each species were constant at all depths and in all areas and seasons. It follows that means can be estimated for the several period–area–depth cells by a procedure using for each species a set of diurnal-interval constants.

For each cell a catch rate has been calculated for each of six 4-hourly diurnal intervals separately, and the sum of these catch rates has been divided by 6 to give a mean value for the cell. For those cells in which there was no catch in one or more diurnal intervals the following procedure was adopted. The mean catch rates of the diurnal pattern for each species were expressed as proportions of the species mean rate, thus, for Bight redfish:

Diurnal Interval	Catch Rate	Proportions of Mean Rate
1800–2200	144	1·1413
2200–0200	168	1·2316
0200–0600	198	1·5693
0600–1000	114	0·9036
1000–1400	66	0·5231
1400–1800	67	0·5310
	Mean 126·2	

The sum of catch rates for each cell in which catches were made in less than six diurnal intervals was divided, not by the number of intervals represented, but by the sum of corresponding proportions. The table of cell catch rates adjusted in this way (Table 19) constitutes the best evidence of variation in catch rate from locality and from time to time.

(*b*) *Catch Rates*

On the 27 cruises, from which detailed records have been kept, the *Southern Endeavour* landed approximately 1,693,500 lb as the result of just over 3800 hr trawling. These values give a gross average catch rate of 3·97 cwt per hour of trawling, or about 3·23 tons per day on the fishing grounds (see Tables 5 and 15). The mean catch rate, 3·97 cwt per hour of trawling lies in a range from 0 to 41·5 cwt per hour, a range of catch rates of individual hauls contributed to by variations in abundance of more than a dozen species. Some aspects of this variation are shown in Table 16, which shows differences between cruises (hence, between months) and between species and is of value for the breakdown of miscellaneous species catch which it gives. Similar information is presented in Table 20, constructed from the captain's tally. This table is included because it presents cruise means drawn from the data that have been submitted to detailed analysis; in considering the means calculated with respect to other variables the reader may find it of value to be able to make comparisons with cruise means. Moreover, the problem presented by the apparent change in retention policy with respect to miscellaneous species can be approached only by considering the miscellaneous species columns of Tables 16 and 20 together.

Certain features of the values of Table 20 should be noted. First, that there was a fall in catch rate after April 1961. Up to October 1960, the total catch rate on all cruises exceeded 4 cwt per hour, and up to April 1961 they stayed high, falling below 3·5 cwt on only two cruises, but on the last 10 cruises the rate exceeded 3·5 cwt only

TABLE 20

CATCH RATES BY "SOUTHERN ENDEAVOUR" ON EACH CRUISE CALCULATED FROM CAPTAIN'S TALLY

Trip	Hundredweight per Hour				
	Bight Redfish	Flathead	Jackass Fish	Other	Total
4	1·92	0·12	1·80	0·77	4·61
5	2·09	0·16	1·96	1·74	5·95
6	1·32	0·02	1·51	1·29	4·14
7	1·04	0·62	3·19	1·67	6·52
8	0·71	0·61	2·00	1·25	4·57
9	1·43	0·14	1·45	2·37	5·39
11	0·86	0·09	0·86	3·37	5·19
12	0·84	0·25	2·11	1·09	4·29
13	1·53	0·19	1·22	1·27	4·21
14	0·95	0·22	1·76	0·84	3·77
15	1·79	0·07	1·61	0·57	4·04
16	1·54	0·14	0·92	0·86	3·46
17	1·58	0·23	1·15	1·74	4·70
18	1·98	0·32	0·97	0·92	4·19
19	1·00	0·20	1·09	0·68	2·97
20	4·60	0·11	0·85	0·01	5·57
21	2·71	0·13	0·99	0·51	4·34
22	0·96	0·16	0·81	0·39	2·32
23	1·30	0·15	0·67	0·85	2·97
24	0·65	0·27	0·66	0·88	2·45
25	0·59	0·84	0·67	0·78	2·88
26	0·56	1·16	0·70	1·16	3·58
27	0·88	0·32	0·98	1·50	3·68
28	0·44	0·24	0·79	1·10	2·57
29	0·45	0·22	0·63	1·26	2·57
30	1·21	0·25	0·67	1·10	3·23
31	0·58	0·24	0·68	0·86	2·36

twice. This is possibly associated with the notable change in catch rate of jackass fish after cruise 15; before this the rate only once fell below 1 cwt per hour and on the average it was about 2 cwt; after cruise 15 it exceeded 1 cwt per hour on only two cruises (out of 16). The possible significance of this is discussed later.

Second, some periodic patterns are detectable in these values. Thus the catch rates for Bight redfish on cruises 4–6 (April–May) are similar to those of cruises 21–23 (April–May) and each set is followed by a set of lower values. Similarly, the flathead catch rates have maxima on cruises 7–8 (June–July) and 25–26, also July; again the miscellaneous species rates have maxima in June to October (cruises 8–15 and 26–30).

Before discussing the catch rates in more detail we would emphasize two points made earlier with respect to the operations and data. First, that the *Southern Endeavour*'s fishing sampled only a small proportion of the total area—perhaps 0·2% in each month. Second, that the captain's tally of catch of the miscellaneous species group was an underestimate of what was actually taken. If all the rejected catch had been recorded, the catch rate would probably have been about 4·5 cwt per hour. For this reason the rates for miscellaneous species in Table 16 are probably truer than those in Table 20, especially from cruise 18 onwards (excepting cruises 17 and 20). It might seem that the percentages in Table 3 (captain's tally over landing) could have been used to adjust the catch rates in Table 20 and the mean rates in Table 19.

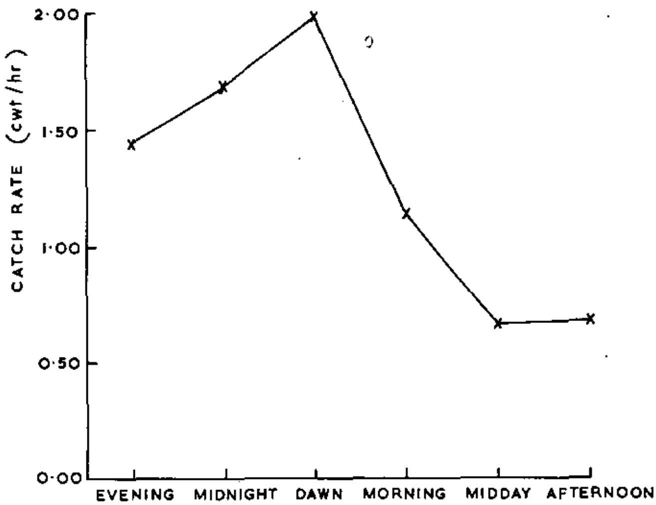

Fig. 4.—Diurnal fluctuation in catch of Bight redfish by *Southern Endeavour.*

However, we believe that we have no reason for supposing that if, by way of illustration, the captain on any cruise "misjudged" the amount of his total catch by, say, 10%, the amount taken on each haul was also erroneously estimated by 10%. The validity of this view can be seen from Table 3 itself in which the discrepance between captain's tally and landing differs from species to species on each cruise: we conclude that if the discrepance can vary from cruise to cruise, and between species on each cruise, it most probably varied also from haul to haul.

The results of the analysis of variance, presented in Table 18(*b*), show a number of significant main effects and interactions. The consequence of these is, as noted earlier, that the most reliable synoptic view of the catch rates obtained by the *Southern Endeavour* is to be obtained from a series of mean values estimated for the cells of a three-way table of period by area by depth. This is presented in Table 19. The diurnal pattern for Bight redfish (discussed above) for which allowance was made in Table 19, is represented in Figure 4.

Values for eastern area in the first period, western area in the third period, and in shallow water central area in the first period have been omitted from Table 19 because in each of these cells the number of hauls at each time-of-day interval was in no case as many as five, in most cases was only one, and in many was nil. Many of these discarded values represent considerable catch rates, e.g. 4·17 cwt per hour of jackass fish, 6·88 cwt per hour of Bight redfish, 4·06 cwt per hour of the miscellaneous species group, 0·56 cwt per hour of flathead.

Marginal mean rates have been included in Table 19, that is, means for each period and for each area, and an overall mean, for each species; in addition, means for each depth and for each diurnal interval, for each species are given in Table 21. However, only the diurnal interval means can be accepted with any confidence and even these must be understood as representing the relative proportions in which the catch over any 24-hr period would be taken from any particular level of abundance. All the other marginal values are subject to some measure of influence from the

TABLE 21

ONE-WAY CLASSIFICATION OF "SOUTHERN ENDEAVOUR" CATCH RATES*

(*a*) Catch Related to Depth

Depth	Bight Redfish	Flathead	Jackass Fish	Miscellaneous
Shallow (50–80 fm)	1·08	0·19	0·81	0·98
Middle (81–89 fm)	1·57	0·28	1·19	1·11
Deep (90–200 fm)	1·11	0·38	1·32	1·27

(*b*) Catch Related to Time of Day

Time of Day	Bight Redfish	Flathead	Jackass Fish	Miscellaneous
1800–2200	1·44	0·32	1·28	1·12
2200–0200	1·68	0·26	0·95	1·28
0200–0600	1·98	0·34	1·09	1·30
0600–1000	1·14	0·33	1·18	1·28
1000–1400	0·66	0·23	1·15	0·73
1400–1800	0·67	0·23	1·04	1·01

* In hundredweight per hour.

demonstrated significant interactions. The extent to which the cell means can be taken to be reliable indices of the abundance of the fish in the places and at the times represented by the cells is a matter discussed in Section VI; judgement on this matter must take into consideration the several aspects of the fishing operations discussed in Section IV, and in particular must attempt an assessment of the consequence of almost no fishing in the eastern area in the first period and in the western area in the third period.

The synoptic view presented in Table 19, although giving, in the form of standard errors, an appropriate measure of the variation of catch rates in each cell does not disclose the frequency with which in fact some very high catch rates were obtained. The frequency distribution of catch rates of each species is shown in Figure 5 and

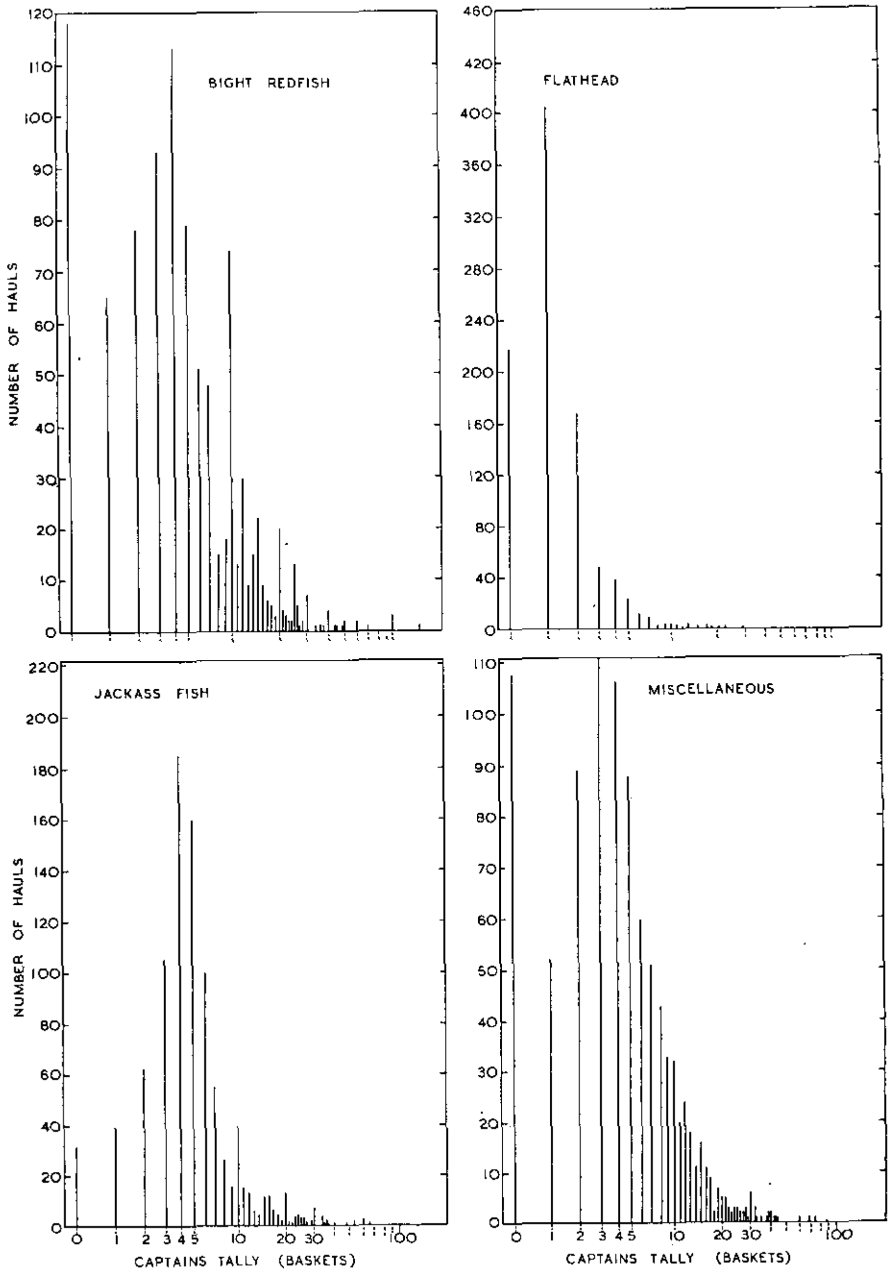

Fig. 5.—Frequency distribution of hauls, classified by baskets taken in each haul. The scale of the abscissa is logarithmic.

Table 22 lists the most notable occasions on which high catch rates were obtained. An important element of fishing tactics is to locate fish concentrations such as those indicated by the catch rates listed in Table 22. More information on the size of such concentrations, and on the frequency of their appearance, would be of considerable value to anyone fishing these grounds, but unfortunately, the *Southern Endeavour*'s operations furnished only the evidence of Table 22 and its results permit no conclusions on these matters. However, Table 22 at least presents evidence that such concentrations do exist on these grounds.

TABLE 22

"SOUTHERN ENDEAVOUR" NOTABLE CATCHES

(*a*) Individual Hauls with High Catch Rates*

Cruise No.	Date	Block	Duration (hr)	Bight Redfish	Flathead	Jackass Fish	Miscellaneous	Total
5	7. v.60	11	4	3·44	0·16	3·60	6·87	14·07
	7. v.60	11	4	5·94	0·31	3·12	4·69	14·06
	8. v.60	11	4	4·37	0·31	4·22	6·73	15·63
7	11. vi.60	20	3¼	0·77	0·38	2·88	13·27	17·30
	12. vi.60	11	4	0·47	0·79	5·16	6·10	12·52
8	11. vii.60	21	3	2·08	0·83	12·50	1·25	16·66
	11. vii.60	21	4	1·87	0·94	4·69	5·00	12·50
	14. vii.60	30	4	1·10	0·62	7·51	3·29	12·52
	14. vii.60	30	4	0·79	1·25	9·37	1·10	12·51
11	7. ix.60	21	4	1·25	0·00	0·00	11·72	12·97
12	2. x.60	21	4	0·31	0·47	10·17	1·56	12·51
13	16. x.60	30	4	7·81	0·31	4·69	1·25	14·06
14	3. xi.60	11	4	2·19	0·16	8·44	1·72	12·51
17	17. i.61	02	3¾	10·00	2·17	2·67	1·83	16·67
20	7. iii.61	50	3¼	28·85	0·20	2·88	0·00	31·93
	9. iii.61	50	3	20·83	0·00	1·04	0·00	21·87
	12. iii.61	41	3½	17·86	0·18	0·89	0·00	18·93
21	30. iii.61	31	4	15·63	0·00	0·62	2·50	18·75
	31. iii.61	31	3	14·58	0·21	1·04	0·83	16·66
25	6. vii.61	21	4	0·31	4·38	1·25	1·87	7·81
	6. vii.61	21	4	0·00	3·43	0·79	1·10	5·32
26	25. vii.61	21	5	0·37	2·51	1·00	1·12	5·00
	27. vii.61	31	4	0·47	3·44	0·47	2·66	7·04

* In hundredweight per hour of trawling.

TABLE 22 (*Continued*)

(*b*) Catch Rates* of Bight Redfish

Cruise No.	Block Numbers							
	20	21	30	31	40	41	50	51
20					5·05	3·93	5·22	3·46
21			2·13	6·37	1·03	2·96	0·33	
22	0·90	1·25	0·43	1·01	1·52	0·31		

* In hundredweight per hour of trawling.

(*c*) *Quantity and Composition of Total Catch*

(i) *The Effect of Fishing Strategy on Total Catch*

As discussed in Section VI(*a*) the outcome of a set of operations, such as those whose results are analysed here, is determined by several sets of factors, as follows:

(1) The pattern of distribution of the stocks, as a whole and with respect to each species separately, and the variation of these patterns with time, diurnally, seasonally, and annually;

(2) The pattern of distribution of effort and the variations in its correspondence with the resource patterns;

(3) The characteristics of the fishing unit and the operational strategy adopted by the captain and any variation in these.

The analysis of data presented in the preceding subsection has identified certain patterns of distribution of the species although these might not correspond exactly with the true patterns. Fishing strategy consists in locating places and times of greatest concentration or vulnerability or both. If the *Southern Endeavour* operations had been carried out so that the hauls had been disposed equally over all areas, depths, and times of day within each season, and assuming that the fish were distributed as indicated in the patterns described above, the average catch would presumably have been 319 cwt per 100 hr trawling, and the total catch would have been only about 82% of what was actually taken. The catch reached its actual level in part from the concentration of fishing in particular areas and depths as indicated in Tables 12 and 13.

As remarked elsewhere in this paper a main element of fishing strategy is the location of high densities of fish and the concentration of fishing on these. An important question to ask with respect to the *Southern Endeavour* operations is: did the captains succeed in a strategy of this kind? The consequence of an affirmative answer to this question would be that the fishing rates would have to be regarded as being characteristic *not* of all the grounds (and their average density) but of selected grounds, perhaps of higher than average density, but not necessarily so. The indication, reported above, that the catch rate might have been only 82% of the actual rate if the effort had been evenly distributed suggests that the very obvious unevenness in distribution of effort might have been decided upon as a strategy. However, this result does not mean that a completely successful strategy was followed. In Table 23 we present calculations of the catches that might have been taken if particular strategies had been followed, based on information of the type presented in Table 19, supposing this to have been available. Thus, if the strategy had been to maximize the catch of Bight redfish, a decision to fish in each period in only that area–depth cell in which the best redfish catch rate was obtained could have given a total catch of Bight redfish of 6844 cwt (84·2% increase), a catch of flathead of 1009 cwt, and catches of 3443 cwt (−12%), and 3518 cwt (−14%) of jackass fish and miscellaneous species, the total catch could have been 14,814 cwt (10% increase). As will be seen from the right-hand column of Table 23, five of these strategies could have given virtually no increase in total catch, six could have given about 7·5% increase, two could have given about 10%, and one could have given 22%.

TABLE 23

CATCHES WHICH MIGHT HAVE BEEN TAKEN BY "SOUTHERN ENDEAVOUR" BY CONCENTRATION OF FISHING IN SELECTED AREA–DEPTH CELLS IN EACH SEASON EXPRESSED AS PERCENTAGES OF ACTUAL CATCHES

Strategy	Bight Redfish (%)	Jackass Fish (%)	Flathead (%)	Miscellaneous (%)	Total (%)
			Bight Redfish		
Best cell	184	88	101	86	110
Best area	138	89	64	84	102
Best depth	123	107	87	95	107
			Jackass Fish		
Best cell	85	123	87	125	108
Best area	84	101	129	123	107
Best depth	87	111	136	120	108
			Flathead		
Best cell	84	117	186	152	122
Best area	79	110	131	104	100
Best depth	88	104	105	116	103
			Miscellaneous		
Best cell	70	73	159	157	104
Best area	98	117	90	116	109
Best depth	89	108	92	118	104

In practice a choice between such strategies would be made with reference to the value of catches of differing composition. On the face of it, if a Bight redfish best-cell strategy would nearly double the catches of Bight redfish (the most valuable), whilst not changing the quantity of the next most valuable fish (flathead), and if a flathead best-cell strategy would give marked increase in the others although giving lower catches of Bight redfish, these might be financially the best strategies.

In sum, the answer to the question posed above is that probably there was some concentration on high densities, but not a total concentration. It may be well to emphasize that the strategies of Table 23 are *not* proposed by us as the strategies that should be adopted by any other vessels which might fish these grounds. Further information about these stocks would have to be obtained before reliable strategies could be planned.

(ii) *Catch Rejected at Sea*

We have discussed earlier the evidence, in the discrepance between "landed catch" records and the captain's tally, that a substantial amount of catch was rejected at sea; on one of the earlier cruises this amounted to as much as 35,000 lb of miscellaneous species. We have also remarked on the often ambiguous record in the "Remarks" column of the fishing log. Scrutiny of these notes allows an estimate for cruises 4–16 of about 1860 baskets (about 130,000 lb) of fish rejected in the course of fishing, but in this estimate only those quantities which the captain has shown clearly as "discarded" can be included and the total might well have been even more than 130,000 lb. The "Remarks" in the logs for cruises 17–31 do not permit an estimate of what was rejected, but, considering that the under-record by the captain of the catch of miscellaneous species was greater on these cruises than on the earlier cruises, as shown in Table 3, we assume that the rejection was less. However, so far as our analysis of the captain's tally is concerned, the retained-but-not-recorded catch (of miscellaneous species) is in the same status as the rejected-at-sea catch. Both result in an underestimate of catch rate. The situation can be summarized as follows:

Cruises	Recorded Catch (lb)	Excess of Landings over Recorded Catch (lb)	Rejected at Sea (lb)	Total Catch (lb)
1–16	230,580	35,432*	130,000	396,012
17–31	259,700	137,115	?	396,815
				792,827

* Includes 35,000 lb jettisoned just before entering port.

The total caught on cruises 17–31 was greater than shown here since the logs indicate that there was rejection although we cannot ascertain its amount. Also the large overestimates by the captain, of miscellaneous species catch on cruises 17 and 20 (see Table 3) might, like that of cruise 11 have resulted from discard at end of cruise, before entering port. In sum it appears to be fairly certain that the catch of miscellaneous species was approximately double that recorded by the captains and in consequence the catch rates in Table 20 are low. Whether this effect operated more heavily in the second and third periods than in the first, and hence would account for much of the apparent difference in these catch rates, cannot be adjudged.

(*d*) *Comparison of* Southern Endeavour's *Fishing Results with those of Other Vessels*

(i) *Vessels which worked in the Great Australian Bight*

Some comparison can be made of the *Southern Endeavour*'s results with those of the *Endeavour* in 1913, and with those of *Ben Dearg* and *Commiles* in 1949–51. The value of the comparison is limited by (1) lack of data by which to assess with accuracy the fishing power of the earlier vessels, and (2) incompleteness of the records preserved from the earlier operations, especially from those of the *Endeavour*.

The main characteristics of all four vessels are given in Table 24. The *Endeavour* was smaller than the *Southern Endeavour* and had much less power, yet she had the same cruising and trawling speeds and carried a trawl with longer head rope. The *Ben Dearg* and *Commiles* were about the same size as the *Endeavour* but smaller than the *Southern Endeavour* and are reported to have had much engine trouble.

The *Endeavour* spent 266 hours trawling in the Bight, but only summary information as to the results of her work has been preserved (Dannevig 1913; Houston 1954). Her catch rate was 1·45 cwt per hour trawling, considerably less than the *Southern Endeavour*'s overall average of 3·97 cwt. However, as remarked we have no way of deciding how much of this difference is attributable to differences between the vessels, to differences in operational patterns and retention policy, or to differences in the stocks in the two periods. The *Endeavour* results on the Bight grounds are of value in an argument with respect to her performance on the east coast grounds, given in the next subsection.

TABLE 24

CHARACTERISTICS OF VESSELS WHICH FISHED IN THE GREAT AUSTRALIAN BIGHT

Characteristics	*Endeavour*	*Ben Dearg* and *Commiles*	*Southern Endeavour**
Length overall	134 ft 9 in.	135 ft	161 ft
Beam	23 ft		29 ft
Moulded depth	11 ft 9 in.		14 ft
Main engine:			
Type	Triple expansion	Steam	Diesel
Power	440 i.h.p.		1200 b.h.p. derated to 1000 at 200 r.p.m.
Speed (kt)	11/2½–3 trawling speed	8–10	11/2½–3 trawling speed
Winch: type			Electric, 279 b.h.p.
rope length	2000 fm, 2½ and 1½-in. wire		800 fm
Trawl: type	Otter		Granton
Head line	95 ft		76 ft
Tonnage	225 approx.†	260	514 gross

* Fish hold: type, insulated to waterline level; refrigerated capacity, 190 tons. Crew: master, mate, eight deck hands; first and second engineers, three greasers, cook and assistant.

† Based on $1 \times b \times d \times 0{\cdot}225$ in metric units.

The data on record with regard to the *Ben Dearg* and *Commiles* are more extensive than those from *Endeavour* though still inadequate. Table 25 gives an analysis, developed from Houston's tables, of the time spent by these two vessels. The data in this table can be compared with those of Table 5. Both vessels spent a considerable amount of time in port (50 and 59%) and this fact alone constitutes much of the answer to Houston's question concerning "(1) why the companies ceased to function".

Southern Endeavour spent 38% of her time in port and even this fell far short of what she had accomplished when working from Great Britian (about 10% in port).

Again, both vessels achieved relatively low effective operating time,* that is with trawl down 38·5% and 38·4% of time absent in contrast with *Southern Endeavour*'s 45%; of total time, the fishing (trawl down) time of these vessels was 19% and 16% compared with *Southern Endeavour*'s 28%. Clearly, then, there is no point in making comparisons in terms of catch per day absent; to do so would be only to emphasize the low performance of the two earlier vessels, a point already recognized.

TABLE 25

OPERATIONS OF "BEN DEARG" AND "COMMILES"
TIME SPENT IN OPERATION AS PERCENTAGES OF VARIOUS CATEGORIES OF TIME USE

	No. of Hours	Total Hours	Percentage		
			T_f	T_a	T
Ben Dearg					
Hours fishing (actual) (less cruise 8)	3609·0		92·22	35·75	17·97
Hours fishing (experimental) (less cruise 24)	304·5		7·78	2·78	1·40
Total fishing = T_f		3913·5	100·00		
Days absent from port (actual)	385			84·25	42·35
Days absent from port (experimental)	72			15·75	7·92
Total = T_a		457		100·00	
Days in port	452				49·72
Total = T (length of operation)		909			100·00
Commiles					
Hours fishing (actual)	2535		95·66	36·93	15·03
Hours fishing (experimental)	115		4·34	1·68	0·68
Total fishing = T_f		2650	100·00		
Time absent from port (actual)	270			94·40	38·41
Time absent from port (experimental)	16			5·60	2·28
Total absent = T_a		286		100·00	
Time in port	417				59·32
Total = T (length of operation)		703			100·00

In comparing catch rates we must take the data from *Southern Endeavour*'s operations in the western sector since according to Houston (1954, Fig. 1), the *Ben Dearg* and *Commiles* operated chiefly in this sector, and we have excluded, for the

* Houston (1954) shows the operating time of these vessels as "fishing time" and since we know the *Endeavour*'s "fishing time" to have been "trawl down" we have assumed that his data for these two vessels were in the same units.

purposes of this comparison, the so-called experimental cruises made by the earlier vessels.

The *Southern Endeavour*'s overall catch rate in the western sector was 4·80 cwt per hour trawl down, which exceeded the overall rates of the other two vessels (*Ben Dearg* 3·08 cwt; *Commiles* 2·46 cwt). Adjusting these values to allow for differences in vessel size, the rates as catch per ton hour were *Southern Endeavour* 1·05, *Ben Dearg* 1·32, and *Commiles* 1·06. We take these values to mean* that, although the *Ben Dearg* had a fishing power, ton for ton, somewhat greater than that of the other two vessels, the results of all three vessels give closely similar indications of the abundance of stocks on these grounds. We take these values further to mean that confirmation of the *Southern Endeavour*'s western sector results increases the confidence we can place in the results in other sectors, and that we can also seek in the results of the earlier vessels some test of the reliability of *Southern Endeavour* results as evidence on species composition of catch, and on seasonal changes in abundance.

TABLE 26

PERCENTAGE COMPOSITION OF RETAINED CATCHES OF VESSELS OPERATING IN THE WESTERN SECTOR OF THE GREAT AUSTRALIAN BIGHT

Vessel	Bight Redfish	Flathead	Jackass Fish	Miscellaneous
Ben Dearg	45·4	7·8	16·9	30·0
Commiles	49·3	5·6	10·3	34·8
Southern Endeavour	30·6	3·9	29·9	35·6

Table 26 gives the percentage composition of the catches retained by these vessels, showing that in the earlier operations the proportion of Bight redfish and flathead in the catch was higher than that in the *Southern Endeavour*'s catch, whereas the proportion of jackass fish was lower. However, there is some question of how well, taxonomically, the catch of "king snapper" by the earlier vessels corresponds with the catch recorded under this name, i.e. of Bight redfish, by the captains of *Southern Endeavour* (see Houston 1954, table 10).

In Figure 6, (*a*)–(*c*) we have plotted the catch rates of each main species and of total, by each of the three vessels, against calendar months; the rates have been calculated for each cruise (Table 27) and each value is entered on the graph at the mid-date of its cruise. These figures show some correspondence in seasonal patterns; maxima in Bight redfish catches appeared in the first 3–4 months of the year; flathead maxima appeared in May–August and October–December, jackass fish maxima appeared in May–July although the lesser maxima in October–November and March–

* This adjustment, which is truly valid only with respect to vessels for which a linear relation of tonnage with fishing power has been demonstrated, might not be valid here; but if it is not, either the *Southern Endeavour* had greater fishing power than the other vessels, in which case her higher catches were due to this and the indication of similar abundances hold, or, which is unlikely, her fishing power was less but she encountered considerably greater abundance.

April in *Southern Endeavour*'s catches of this species did not appear in those of the other vessels; the value for miscellaneous species catch is too confused for interpretation; in the value for total catch there is quite a lot of correspondence.

In sum, the data from the *Ben Dearg* and *Commiles* operations correspond in important respects with those from the *Southern Endeavour* and seem to lend substantial support to the interpretation of the analysis of the *Southern Endeavour* data.

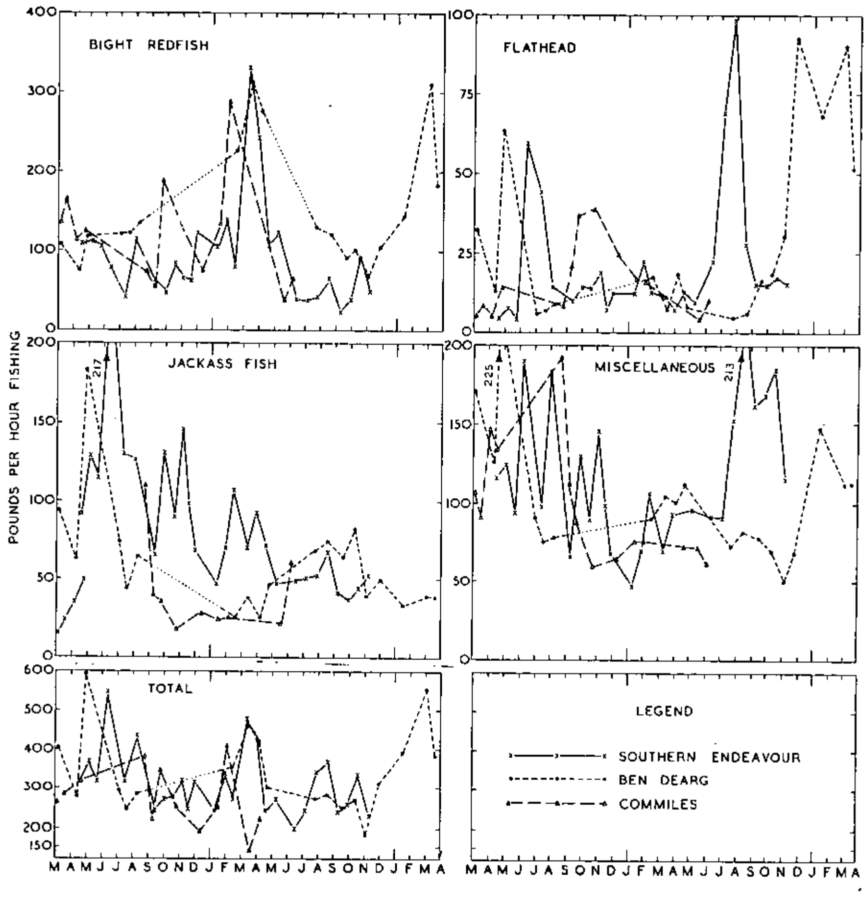

Fig. 6.—Monthly catch rates by *Southern Endeavour* (1960–61), *Ben Dearg* (1950–52), and *Commiles* (1950–51) in the Great Australian Bight.

(ii) *Comparison of Fishing Rates with those obtained on other Grounds*

The discussion of the preceding section is an approach to the standard method of examining the performance of one or more vessels, namely a comparison of the results from similar vessels on common ground; preferably such comparison should be made of operations at the same time, but this was not the situation in the Bight operations. Another approach is to compare the results from the same vessel, or similar vessels, on different grounds. For this purpose the *Southern Endeavour*'s fishing rates can be compared with rates obtained on other Australian grounds, namely those of the east coast, and with rates obtained on demersal grounds in other parts of the world.

TABLE 27

CATCH RATES* ON CERTAIN CRUISES BY "COMMILES" AND "BEN DEARG" WHEN OPERATING IN THE GREAT AUSTRALIAN BIGHT

Cruise No.	Effort (100 hours trawl down)	King Snapper	Flathead	Morwong	Other	Total
			(a) Commiles			
8	1·94	1·36	0·05	0·15	1·07	2·63
9	1·90	1·64	0·09	0·24	0·90	2·87
10	1·69	1·14	0·05	0·36	1·47	3·02
11	1·29	1·23	0·14	0·50	1·34	3·21
13	1·10	0·74	0·09	1·09	1·92	3·84
14	0·46	0·54	0·21	0·40	1·11	2·26
15	1·38	1·88	0·37	0·35	0·87	3·47
16	1·24	1·38	0·39	0·18	0·60	2·55
17	1·16	0·75	0·25	0·29	0·64	1·93
18	1·16	1·34	0·17	0·25	0·76	2·52
19	1·65	2·87	0·21	0·25	0·75	4·08
20	0·96	0·38	0·05	0·21	0·81	1·45
21	0·85	0·65	0·10	0·61	0·88	2·24
			(b) Ben Dearg			
9	1·57	1·09	0·32	0·94	1·72	4·07
11	1·87	0·75	0·13	0·64	1·26	2·78
12	0·87	1·19	0·64	1·83	2·25	5·91
15	1·32	1·23	0·07	0·74	0·90	2·94
16	1·74	1·21	0·07	0·44	0·75	2·47
17	1·06	1·35	0·10	0·64	0·78	2·87
20	1·75	2·26	0·17	0·26	0·90	3·59
21	1·72	3·12	0·07	0·38	1·04	4·61
22	1·49	2·77	0·19	0·25	1·01	4·22
23	1·35	1·32	0·08	0·46	1·12	2·98
27	1·44	1·29	0·04	0·68	0·72	2·73
28	1·31	1·20	0·06	0·74	0·81	2·81
29	1·38	0·91	0·17	0·64	0·77	2·49
30	1·58	1·02	0·19	0·83	0·69	2·73
31	0·70	0·68	0·31	0·39	0·49	1·87
32	0·90	1·06	0·93	0·50	0·68	3·17
33	1·46	1·43	0·68	0·33	1·48	3·92
35	1·41	3·10	0·91	0·39	1·13	5·53
36	0·93	1·83	0·52	0·38	1·14	3·87

* In hundredweight per hour.

The results of the *Endeavour* are of special interest since this is the only case in which records are available from a vessel which fished both grounds. The values given by Houston (1954) in his table 3 (constructed from the text of Dannevig 1913) show an east coast catch rate of 2·25 cwt per hour trawl down, contrasted with

1·45 cwt per hour trawl down, taken by this vessel on the Bight grounds. This might be taken to mean that the east coast grounds in those years carried stock whose abundance was some 56% greater than that of stock on the Bight grounds. However, this deduction is unacceptable for a number of reasons. First, the east coast figure from the *Endeavour* was the result of operations during 4⅓ yr (April 1909 to August 1913), which was enough for knowledge of the grounds, and especially of the best grounds, to have accumulated. Moreover, the operating conditions on the east coast were, compared with those in the Bight, favourable to return to and continued operation on selected grounds. The *Endeavour*'s Bight results, obtained from operations during 1½ yr, are more validly contrasted with the first 1½ yr of work on the east coast. In the period January 1909 to June 1910, the *Endeavour* made 21 cruises on the east coast and in the course of 279 hauls, which took 475 hr, caught about 101,000 lb of marketable fish, a catch rate of 1·90 cwt per hour trawl down. Second, the area in the Bight surveyed by the *Endeavour* (with only 266 hr of trawling compared with 661 hr on the east coast) was very considerably greater than that surveyed by it on the east coast. The logs published by Dannevig (1909, 1910) show that some of this work was outside the area from which the *Southern Endeavour* data were obtained, and in very shallow water. The difference between the *Endeavour*'s Bight catch rate (1·45 cwt per hour trawl down) and her east coast catch rate (1·90 cwt) therefore might not carry much significance. For these reasons it seems valid to regard the *Endeavour*'s Bight results as being of more exploratory nature than her total results on the east coast.

Employing further the argument above with respect to accumulation of experience, and acknowledging Houston's (1954) prediction that later fishing in the Bight might show the same development as took place on the east coast, we have constructed Table 28. The years 1928 and 1942–43 have been included because they were peak years and we may note that the first peak, reached after 14 yr of continuous commercial operation, was not a great deal more than the *Southern Endeavour*'s annual rate. In fact over the years 1915 to 1954, the east coast vessels achieved a catch rate greater than that in Table 28 for *Southern Endeavour* in only 9 yr. In terms of catch per hour the *Southern Endeavour* rate was not exceeded at all on the east coast over the period 1945–54.

Due weight must of course be given to the fact that the east coast catch for many years consisted largely of flathead and that, according to reports, much fish was rejected at sea from these operations. We have already recorded a view (Section V(*b*)) that the total catch by the *Southern Endeavour*, including catch rejected at sea, might have been in excess of 4·46 cwt per hour, but no similar value with regard to east coast operations has been published. On the other hand if we consider only the catch of the more readily marketable and generally more valuable fish, we may note that the overall mean rate of catch of Bight redfish, flathead, and jackass fish by the *Southern Endeavour* was 2·72 cwt per hour, a rate not often exceeded on the east coast.

Houston (1954) made various comparisons between east coast and Bight data, including one with respect to catch per day absent from port. Still others could be made by reference to data in Fairbridge's papers (1948, 1951*a*, 1951*b*), such as catch per trawler ton. However, in the absence of detailed analysis of east coast data further comparisons are inadvisable. The various comparisons already made, however, point to similarities between the history to date of operations in the Bight and the history in the 1910's on the east coast, and, with such indications as the analysis reported here gives of resources in the Bight, lend support to an expectation, as expressed by Houston (1954) that a fishery in the Bight might follow a course similar to that of the east coast—in the sense, that is, of developing on the basis of accumulated experience.

Only one further point need be mentioned. Fairbridge (1948) referred to the catches made on the *Botany* grounds of the east coast, which were quite phenomenal for a few years, reaching at times more than 17·86 cwt per hour. An important feature of these catches was that they were maintained for some time. The fact that the *Southern Endeavour* made a few hauls at these high rates is not evidence that concentrations exactly like those of the *Botany* grounds exist in the Bight, but they suggest the possibility of their existence.

TABLE 28

SOME CATCH RATES FOR BIGHT AND EAST COAST FISHING GROUNDS SINCE 1909

Year	Vessel	Catch Rates	
		Hundredweights per Hour	Hundredweights per Vessel Year
	Bight Grounds		
1909–10	*Endeavour*	1·45	
1930	*Bonthorpe*	2·81	
1950	*Ben Dearg* and *Commiles*	4·66	4484
1960–61	*Southern Endeavour*	3·97	8721
	East Coast Grounds		
1909–10	*Endeavour*	2·25	
1915–16	State enterprise	2·28	4852
1928	Private operators	(2·76)	10 378
1934	Private operators	(1·50)	5651
1942–43	Private operators	(3·52)	13 245

Finally, from a practical viewpoint we may examine the rates at which fish is landed in some overseas fisheries as evidence of the catches on which fishing is conducted for commercial profit (Table 29). For this purpose we use catch per 100 trawler ton hours since trawler ton hour certainly has a close relation with operating costs, even if the meaning of this catch rate with respect to abundance might be a little uncertain. The data in this table are presented only as examples of catch rates of various species—not for entire fisheries. It will be seen that with the exception of the arctic fisheries few of these fisheries had catch rates in excess of those obtained by the *Southern Endeavour*.

VI. Fish Stocks of the Bight Grounds

The analysis discussed in the preceding section has permitted a statement as to the results of the *Southern Endeavour* operations, with a minimum of extrapolation from them. The evidence, found in these results, of the likely patterns of catch rates could be of value to any other captain who might take a trawler onto these grounds. However we must proceed beyond this, seeking in these results some evidence as to the abundance of the stocks on these grounds. Evidence of this kind could serve as basis for estimates of the prospects of developing commercial fishing operations in the *Bight*.

TABLE 29

CATCH RATES* OF "SOUTHERN ENDEAVOUR" COMPARED WITH RATES IN VARIOUS NORTHERN HEMISPHERE FISHERIES†

(*a*) *Southern Endeavour*

Bight Redfish	Flathead	Jackass Fish	Miscellaneous	Total
0·25	0·05	0·21	0·22	0·73

(*b*) English and Scottish Vessels

Fisheries	Region I		Region II*A*		Region II*B*		Region V*A*		Region V*B*		Region IV*A*	
	1961	1962	1961	1962	1961	1962	1961	1962	1961	1962	1961	1962
NE. Arctic cod	1·28	1·50	0·94	1·08	2·06	2·18						
Haddock; distant waters	0·47	0·38	0·58	0·70	0·05	0·04	0·46	0·49	0·23	0·31		
Saithe	0·03	0·02	0·16	0·16	0·01	0·09	0·09	0·39	0·33	0·32	0·41	
Redfish	0·06	0·06	0·16	0·14	0·07	0·07	0·09	0·10	0·005	0·005		

* In hundredweights per 100 trawler ton hours.

† From Fridrickssen (1962).

(*a*) *General Considerations*

(i) *The Use of Catch-per-unit-effort as Index of Abundance*

The main premise on which arguments from catch rates to stock density are based is that the catch taken in a single operation of a gear such as a trawl net is a direct index of the abundance of the fish on the ground over which the gear has been hauled. This premise can be represented by the following equation:

$$c = D \times q \times a \qquad (6)$$

in which c = catch;* q = the proportion of the fish in unit area, retained by the particular net; D = number of fish per unit area; a = area over which the trawl is drawn (swept area) in a single operation or unit of time; i.e. the catch taken in a single operation is related to the density of the fish on the ground in the proportion

* c Denotes catch from individual units of effort; C denotes any derived estimate of catch, e.g. totals.

q which is a function of characteristics of the gear and of the behaviour of the fish in reaction to the gear. From equation (6)

$$c/a = qD. \tag{7}$$

The term a can be regarded as synonymous with "unit effort", because in trawl fishing the records are in terms of hours of trawl on the ground and the trawling of a unit of time means a unit of area swept. The effort in trawl fishing is essentially a matter of "swept area" which is the product of the spread between the otter boards and the length of the haul; taking the spread and trawling speed to be constant for a particular fishing unit, variation in "swept area" will come from variation in haul duration. If these assumptions are correct we may take a value "duration of haul" for each haul as directly related to swept area, and the term on the left of equation (7) stands for "catch per hour" of trawling. It is true that net spread varies in response to variations in towing speed and other factors, and that towing speed itself varies both in response to engine room controls and to currents and so forth on the ground. However, there are no data from the "*Southern Endeavour* operations" which could permit adjustment of trawl time to ensure constancy of the relation of trawl time and swept area. As a result, our values of c/a ($= c/f$ where f is effective effort) must have some variance attributable to actual variations in net spread and towing speed.

The term "swept area" refers to a two-dimensional unit whereas a trawl is of course three-dimensional, and fish on a ground must have some vertical extension. If the fish are distributed through the water some distance vertically then the variations in the gap of the net will introduce further variance in our values of c/a. If the fish have vertical distribution whose variation can influence the rate of fishing the term a in equation (6) should stand for volume. Again we have no way of adjusting for this factor, or even of knowing whether adjustment should be made.

The term q cannot under present conditions be measured from the data of a single vessel fishing a virgin stock for a short period. In most work in this subject the term q stands for both a and q in equation (6) and a term relating a to the total area occupied by the stock. Thus Gulland (1964) says that variations in q may be classified in two ways, firstly according to direct causes of variation; secondly according to its relation to other factors. In the first way of classification he names three causes:

(*a*) Changes in the proportion of the total area inhabited by the stock which is covered by the unit of nominal effort, i.e. the area "swept" by the gear. This is equivalent to changes in *fishing power*. (For some gears, e.g. trawls, the "swept area" is literally the area covered by the trawl while being towed; for the searching type of gear, e.g. purse seines, the area covered by actual operation of the gear is less important than the area searched by the ship before shooting the gear.)

(*b*) Changes in the proportion of fish within the area "swept" by the gear which are in fact caught by the gear, i.e. changes in vulnerability to the gear.

(*c*) Changes in the probability that the selected fish lies within the area swept by the gear. If the fish or fishing effort were randomly distributed this probability would be equal to the ratio of swept area to total area inhabited by the stock, but in practice, of course, fishing is concentrated in the more densely inhabited areas. A distinction may be made between this effect in a small area (e.g. on a particular fishing ground)—the aggregation of Gulland (1955)—and that in the area inhabited by the whole stock—the *concentration*.

Cause (*a*) here corresponds to a and cause (*b*) to q, in equation (6). In an analysis of variance of individual hauls cause (*c*) is part of the variation in D that we wish to ascertain and measure. Gulland's second way of classification covers five types of change in q:

(i) changes with the amount of fishing,
(ii) changes with the stock abundance,
(iii) long-term changes, or trends, in time,
(iv) cyclical changes (seasonal or diurnal changes),
(v) random or irregular changes.

For our purposes we take this to be a list of kinds of change which may take place in fish–gear relation, and which determine q as we have defined it in equation (6). The data from the *Southern Endeavour* may permit identification of one or two such changes in q. For example, a pattern of diurnal change in c/a observed in the catches of a single species in a small area over a short period could be due to a diurnal pattern of behaviour within that area; however, it could reflect a diurnal pattern of movement into and out of the fished area (or volume), and thus be a change in the accessibility rather than of the vulnerability of the fish to this gear. This matter is discussed in Section V, and Gulland's list is quoted here chiefly to indicate the possible variability of q of whose presence we must be aware.

In the treatment of this matter by Beverton and Holt (1957) and by other authors subsequently, the value of q, in the sense in which Gulland (1964) discusses the term, is estimated by plotting Z (instantaneous total mortality coefficient) against f (effective effort) or g (recorded and uncorrected effort). A linear regression is then calculated and the intercept, corresponding to no fishing, is taken to be a measure of M (instantaneous natural mortality coefficient). On the ground that $Z = F+M$, and on the assumption that M remains constant, the abscissa is raised to the level of M and the regression coefficient is taken to be q, that is

$$F = qf, \tag{8}$$

where F is the instantaneous mortality coefficient.

We do not wish to challenge here the assumptions of this procedure, but to point out its inapplicability in our situation since the procedure can be applied only when f (and hence F) varies to a degree, and over a period, sufficient to permit calculation of the regression.

If D could be measured directly then q could be calculated from equation (7), but although advances toward this, using echo-sounding equipment, are well under way, no such method was employed in the *Southern Endeavour* operation.

The situation then is that we have a set of values of c/g obtained in various localities identified geographically, and characterized as to depth. In addition we know the time of day, and the date on which each haul was made. Our task is to analyse this set of values and estimate the average value of D at various times and places and to prepare a plausible account of its variation, bearing in mind that trawling time does not have a constant relation with area swept, and that variation in factors determining q cause our values of c/g to have a varying relation with D. We have then to go further, if possible, to estimate the size of the stock (P) and of the catch that might be taken from it. This we have to do for the three species recorded separately by the captain, for the miscellaneous species catch and for total catch.

If the trawl took a constant proportion, or all of the fish in its path (q constant or 1) the variation in c/a for a series of hauls would be the variation in density of the fish in space and time. Our work is complicated by the fact that neither condition holds. However, one purpose of the preceding discussion, and especially of expression (7), has been to emphasize the distinction between those factors, in this system, residing in the fishing equipment and those residing in the resource. This is the purpose of separating a and q in equation (6) and for stressing that we seek to deal with values of c/a relating to values of qD having q as defined in identity (7), and not with values of c/f related to values of qD having q as defined by Gulland. Although the arithmetic of the operation differs little, if at all, from that employed by other workers, there is a difference, we believe, in what we are talking about. This is of importance when we move from our analysis of our estimates of qD to some estimates of P. For this purpose we take yield (Y) for whatever time–space cell appears convenient and remembering that $D = P/A$, we can rewrite equation (1) as

$$Y = \frac{a}{A} \times t \times q \times P \times E, \tag{9}$$

in which E is a random element with zero mean, and t is the number of operations or of trawling hours depending on whether a is area per operation or per hour. In this form a will be given a value estimated by us for a unit of operation—we use an hour of trawling. The term A will have the value we find for the total area we are considering for each time–space cell. Our values for Y, a, A, and t thus have factual basis, Y and t being direct record, whilst a and A are estimates. The term a/A is a small fraction and the product $a/A \times t$, gives an estimate of the upper value of F, obtained more correctly from the expression

$$e^{-F} = [1-(a/A)]^t. \tag{10}$$

The true value of F will be less than this by the amount that q is less than unity.

(ii) *The Problem of Patchiness and Varied Duration of Haul*

We have argued that our term a can be taken to be directly proportional to swept area although we must admit that conditions affecting the speed of the vessel may cause it to travel in an hour a distance sometimes shorter and sometimes longer than average; we also admit that conditions may cause the net spread to be less or more than the average, both vertically and horizontally. However, lacking measurements of speed and spread we have had to assume a direct proportionality.

We have also had to assume that the trawl encounters, on each occasion it is down, one common density over the whole length of its sweep, and hence that on each occasion (and therefore for each density), the longer the haul the greater the catch. The validity of this assumption can be affected by a patchiness in distribution of the fish especially if density can vary from patch to patch and if the captain should vary his haul length. In any series of hauls varying in length it could easily happen that the shorter hauls encountered a smaller proportion of unoccupied ground than was encountered by the longer hauls; the densities on the patches encountered by the shorter hauls could also be greater; under circumstances such as these the catch per unit time of the short hauls would be greater than that of the longer hauls; the effect might be so great as to give greater absolute catch for shorter hauls. Of course the reverse could also happen, and over an extended series this effect could reasonably be expected to average out. However, if a captain can judge the weight of catch in the net whilst it is still on the bottom, and should determine the length of haul on his judgment of catch (having an upper limit beyond which he would not prolong his haul), then hauls would be shorter than average when and *because* a good catch had been made, whereas full length hauls would have run to full duration, at least for some large proportion of them, because there was no indication that a good catch had been made. Hence the shorter hauls would on the average show greater catch rates and possibly greater absolute weight of catch.

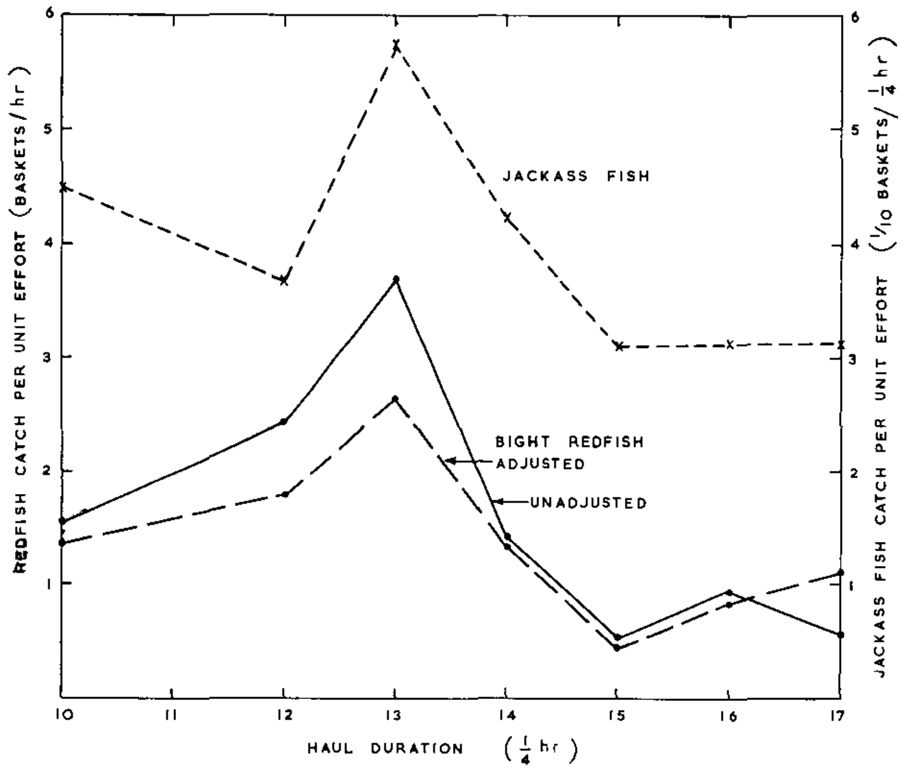

Fig. 7.—Relation between catch rate and duration of haul in *Southern Endeavour* fishing for Bight redfish and jackass fish. The redfish values shown on the broken line have been derived by using an adjustment based on the diurnal cycle.

In a planned prospecting operation the appropriate strategy would be to make all hauls to be of the same length as nearly as possible or, if haul duration should be varied, this should be done independently of the factors determining abundance. In commercial operations the strategy would be to adopt a haul duration appropriate to patchiness (average width of patch and average distance between patches) and to adjust length of each haul on evidence (in warp behaviour) of catch being taken, thus allowing for differences resulting from whether a haul began on a patch or on a between-patch area, and for differences of density on the patches. The consequence of this strategy, if successful, is to give an estimate of density which is too high for the total area, the degree of overestimate depending perhaps in some measure on the proportion of short-duration hauls in the total number of hauls.

Some evidence of this effect was apparent in the *Southern Endeavour* data, as shown for season 2, eastern area, middle depth, in Figure 7. In this time–place cell, 75 hauls were made, obtaining a catch of 1495 baskets of Bight redfish, or about 20 baskets per haul; however, on four of these, the catch was 100, 150, 100, and 100 baskets, an average of 112·5 baskets per haul; for the remainder the average was 14·7 per haul. In terms of hundredweight per hour trawl down these values are 15·63, 25·00, 20·83, and 17·86 for each big haul with 20·45 as their average, whilst the average of the remaining, small hauls is 2·53 cwt per hour. The average catch rate in

TABLE 30

"SOUTHERN ENDEAVOUR" CATCH RATES* OF SECOND SEASON IN EASTERN AREA AT MIDDLE DEPTHS

Duration Interval (hr)	Number of Hauls	Mean Catch Rates†				
		Bight Redfish			Jackass Fish	
		(1)	(2)	(3)	(1)	(2)
2½	2	3·87	3·87	3·15	1·12	1·12
3	14	6·06	4·92	4·32	0·92	0·92
3¼	4	9·28	2·76	7·30	1·45	0·96
3½	16	3·55	2·60	3·05	1·06	0·88
3¾	3	1·30	1·30	1·01	0·78	0·78
4	35	2·33	1·94	2·29	0·79	0·75
4¼	1	1·47	1·47	2·77	0·79	0·79
General means		3·64		3·41	0·92	

* In hundredweight per hour.

† Means: (1) Simple mean of all hauls in each duration interval; (2) as (1) except that four large catches are removed; (3) values of (1) adjusted for diurnal cycle.

each duration interval, shown in Table 30, was greater for short duration than for long, whether on simple means (column 1) or adjusted for diurnal cycle (column 3). The large hauls were made in 4, 3¼, 3, and 3½ hr respectively; admittedly not convincing evidence of a deliberate strategy to shorten the hauls when catches are large. But if we remove the values for these catches from the calculations the short duration hauls still gave greater catch rates than did the longer duration. Although the catch rates of hauls of 2½, 3¼, 3¾, and 4¼ hr are suspect because of small numbers of hauls taken in these intervals, it might well be that about 3 hr was the commercial optimum haul duration for the pattern of distribution of Bight redfish in this time–space cell. It will be seen in Table 30 that much the same result emerges for jackass fish. For this species the average catch of the 75 hauls was 5·1 baskets; most hauls were under 10, but six were 15(3¼), 11, 10, 10(3½), 10, 12(4) (the numbers in parentheses are haul duration in hours); removing these gives an average of 4·6 baskets per haul. Converted, as above, to hundredweight per hour trawl down, these amounts are 2·88, 1·96, 1·79, 1·79, 1·56, and 1·88, for each big haul; and 0·79 is the average of the remaining, smaller hauls. The flathead hauls were generally 1 or 0, and although four were greater (4, 2, 2(4), 2(2½)), chiefly in the longer haul duration, there was greater catch rate at short haul than long. Converted to hundredweight per hour trawl down, these amounts are 0·63, 0·31, 0·31, and 0·50. In the case of the miscellaneous species group, all three longer hauls (greater than 10 baskets) were made at the 4-hr interval. In general the conclusion must be that the patchiness was such as to be likely to give larger catch rates for short duration hauls than for long, and that possibly a haul of 3–3½ hr was better suited to the patchiness of Bight redfish and jackass fish than one of 4 hr or longer. However over all the operations, more hauls were of 4 hr or longer (about 57%) and it may be assumed that the mean values obtained by averaging over all duration intervals give a fair indication of density, or, if anything, a low and not a high estimate.

(*b*) *Composition of the Stocks*

The evidence on composition of landings and of catch is summarized in Table 31. The percentage values for the cruises of the first two periods are similar in the three parts of the table, but for the third period those calculated from landings differ from those calculated from the captain's tally; we take this difference to result chiefly from the greater retention of the miscellaneous group in the third period (see Section V(*c*) (ii)). For this reason we would consider that the miscellaneous species catch of the first two periods should be accorded a greater percentage and the catches of the three main species lesser percentages. This would have the effect of making the percentages of the first and second periods nearer the percentages of the third period calculated on landings, but would not remove the very high value for redfish in the second period nor that of flathead in the third period; on the other hand it would make the flathead percentages of the first and second periods even lower. A comparison of the *Southern Endeavour* results in this respect with those of the *Ben Dearg* and *Commiles* is given in Table 26, dealing with catches in the western sector. The Bight redfish and jackass fish percentages of the *Southern Endeavour* differ considerably from those of the other vessels, and if we follow the argument above with respect to miscellaneous species the Bight redfish difference would be accentuated while that of jackass fish would be reduced. The *Southern Endeavour*'s Bight redfish percentage in the second period was close to that of the other two vessels, which would seem to mean that such preponderance of Bight redfish appearing at various times is characteristic of these grounds. Whilst the general impression from the *Southern Endeavour* results is that Bight redfish and jackass fish are present in about the same abundance (with miscellaneous species, as a group, more abundant, and flathead abundance only about a quarter of that of the other two species), there is indication in the detailed record of the logs, and in the synoptic tables (e.g. Table 19) of patchiness, of some substantial concentrations, and perhaps of migration effects.

With respect to the last point, Table 22(*b*) shows a shift of area of concentration of Bight redfish in the course of three cruises, and at the same time a fall in abundance. Although this is slight evidence on which to base a postulate of massive population shift, it might well be that such a shift takes place and that the period effect demonstrated in the analysis of variance had its origin in this in consequence of the lack of fishing in certain areas in certain periods. Moreover, significant interactions of depth with area and period were demonstrated and can be seen in Table 19, showing that the Bight redfish are present in all depths of the fished area but vary in abundance between depths, being in greatest abundance in shallow water in some areas and some times and in deep water at other areas and times.

TABLE 31

SPECIES COMPOSITION OF THE CATCHES OF THE "SOUTHERN ENDEAVOUR" LANDINGS

Cruise No.	Bight Redfish	%	Flathead	%	Jackass Fish	%	Miscellaneous	%	Total
				Recorded Landings (cwt)					
4–15	1257	23·9	296	5·6	1931	36·7	1779	33·8	5263
16–23	2474	48·4	179	3·5	1143	22·4	1311	25·7	5108
24–34	827	17·4	591	12·4	826	17·4	2507	52·8	4750
Total	4558	30·1	1067	7·1	3900	25·8	5597	37·0	15 121
				Captain's Estimate (cwt)					
				(a) All effective hauls, including those with gear damage					
4–15	1429	25·0	289	5·1	2116	37·0	1883	32·9	5716
16–23	2287	49·4	199	4·3	1092	23·6	1047	22·6	4626
24–31	885	22·7	582	14·9	987	25·3	1448	37·1	3902
Total	4601	32·3	1070	7·5	4195	29·5	4378	30·7	14 244
				(b) All effective hauls used in analysis					
4–15	1347	25·4	269	5·1	1946	36·8	1731	32·7	5293
16–23	2275	49·4	198	4·3	1087	23·6	1044	22·7	4604
24–31	816	22·9	534	15·0	886	24·8	1331	37·3	3567
Total	4437	33·0	1002	7·4	3918	29·1	4106	30·5	13 464

The overall mean catch rates given in Table 19 show the relative abundances of the species in the ratio 1 : 0·22 : 0·81 : 0·93 (Bight redfish to flathead to jackass fish to miscellaneous species). These ratios differ importantly from those calculated with respect to landings by trawlers on the east coast in which for many years flathead was the dominant species. However it must be noted, as pointed out in Section VI(*c*)(iii) below, the flathead of the bight is of a species different from that of the east coast. More than 50 species of fish have been taken in the Bight; to most of these there are species on the east coast grounds, which are closely related—some species inhabit both grounds. Taxonomically the stocks of the two areas appear to be closely similar, but this resemblance affords only slight basis for assumptions as to the yielding capacity of the Bight stocks. However, anticipating the section that follows we may note that the main species on the Bight grounds display biological characteristics similar to those shown on east coast grounds.

(c) *Some Biological Data on the Bight Stocks*

Very few biological samples were taken in the course of these operations, and these were from only a few of the cruises, giving inadequate coverage over the period of investigations.

During the time span of operations, there were considerable changes to the gear. The change most likely to have significant effect on fish size was a switch in January 1961 from 5-in. mesh in the cod ends to $3\frac{1}{2}$-in. mesh. The experience of mesh experiments carried out elsewhere in the world suggests that such a change should have made a major change to length distributions and the fact that very little change took place in the length distributions of the Bight work must be indicative of certain characteristics of the Bight populations.

Only the three most important species (commercially) were sampled, i.e. Bight redfish, jackass fish, and flathead. From most samples only length of individual fish was taken and the recorded data are in the form of length frequencies; on a few samples detailed biological observations and measurements, such as sex, gonad weight and stage, weight and gutted weight were taken. Occasionally stomachs or gonads or both were retained and preserved for biological investigation.

(i) *Bight Redfish,* Trachichthodes gerrardi

Samples were taken during cruises in both 1960 and 1961. The results, broadly, in length frequencies are as follows:

	1960	1961
Mean (cm)	36·1	35·3
Mode (cm)	37	36
Range (cm)	16–53	16–55
Average weight (lb)	3·28	3·06

On the east coast of Australia, trawlers (using a $3\frac{1}{4}$-in. mesh in the cod end) catch nannygai (*Centroberyx affinis*), a species closely resembling *T. gerrardi,* in a size range of 15–35 cm with a mode at 24 cm. Since in the Bight operations there was very little sorting at sea, difference between the catches in the Bight in 1961 and the catch on the east coast using almost the same mesh size is completely anomalous in terms of mesh selection and appears even more peculiar when it is realized that no significant change occurred in the length distribution when a change was made from a 5-in. mesh to a $3\frac{1}{2}$-in. mesh cod end. It has been noticed on the east coast that the size range of catches of nannygai tend to be small; the inference is that the fish school by size. Possibly the same mechanism is in operation in the Bight and on the cruises from which the catch was sampled only one size group had been caught, differing from the size group commonly caught on the east coast grounds. Of the fish sampled the sex ratio was 57 : 43, the average lengths over the two years being females 35·9 cm and males 36·8 cm. The difference between round weight and gutted weight is approximately 49 g in females and 38 g in males, a difference largely due to a difference in 8 g between the gonads of the females (10 g) and males (2 g).

Many of the fish in the sample had empty or very nearly empty stomachs. Small squid, crustacea, copepods, shrimps, small fish, and eels were the only recognizable food matter amongst the shell grit.

(ii) *Jackass Fish*, Nemadactylus macropterus

Samples were taken during cruises in 1960 and 1961. The data with respect to fish caught can be summarized as follows:

	1960	1961
Mean (cm)	33·6	36·2
Mode (cm)	34	36
Range (cm)	24–48	24–60
Average weight (lb)	1·5	1·6

This species is caught on the east coast grounds by trawlers using a $3\frac{1}{4}$-in. mesh cod end. The length distribution has a size range from 18 to 48 cm with the modal group varying between 18 and 48 cm and weight approximately 1·2 lb. The difference in sizes caught in the two fisheries is reasonably consistent with the mesh size difference and the fact that the Bight fishing was on virgin grounds.

Of the fish in the samples the sex ratio was 53 males to 47 females, with a tendency to catch a greater proportion of males among the small fish and of females among the large fish.

Most of the fish in the samples had empty stomachs but others had a variety of crustacea, molluscs, echinoderms, shell grit, and small fish.

(iii) *Flathead*, Neoplatycephalus speculator

The species taken on the east coast trawl fishery is *N. macrodon*, but such is the similarity in body proportions between *N. speculator* and *N. macrodon* that the two species can be expected to be subject to the same selectivity in fishing. The samples of 1961 were taken with a $3\frac{1}{2}$-in. mesh cod end and the results can be usefully compared with samples taken with a $3\frac{1}{4}$-in. mesh cod end used on the east coast since 1955. Before 1955 the mesh size used on the east coast varied from $2\frac{1}{2}$ to 3 in. and between 1946 and 1954 the modal size group taken was 32–33 cm. From 1955 to 1964 the modal size group has varied from 35 to 40 cm. From the Bight grounds, the modal size group was at 48–50 cm with an average weight of 2·2 lb compared to an average weight of approximately 1·2 lb from the east coast. The seeming inconsistency of these results can be explained by the fact that the Bight trawling was carried out on virgin grounds.

(*d*) *Density and Magnitude of the Bight Stocks*

Following the argument of Subsection VI(*a*) tentative estimates of fishing rate have been made in terms of the area swept by the trawl used by the *Southern Endeavour;* this was a 76-ft headline short Granton type which, following Parrish and Kier (1959), has a swept area per hour of 0·1756 sq. nautical mile when towed at a speed of 3 knots; for the average haul duration of 3·72 hr the swept area is 0·6535 sq. nautical mile. A calculation can then be made, using equation (10), for each of the cells in Table 19, and putting

$a = 0 \cdot 6535$, i.e. area swept per haul,

$A =$ the corresponding cell area value from Table 14,

$t =$ the corresponding cell number of hauls from Table 14.

The results of these calculations are given in Table 32. In these calculations we have taken q to have a value of 1, and hence these estimates are, in this respect, maximum values. It is unlikely that q ever reaches this value since authors believe (see Kreuzer 1964) that a trawl captures and retains between 10 and 60% of the fish in its path, varying from species to species. If the true values for q, for the species in the Bight and for the gear used by the *Southern Endeavour*, should lie in this range of 10–60%, the estimates in Table 32 are from 1·6 to 10 times the true values.

TABLE 32

FISHING MORTALITY COEFFICIENT OF "SOUTHERN ENDEAVOUR" OPERATIONS IN THE GREAT AUSTRALIAN BIGHT

Period	Depth	Area			Mean Values at each Depth in all Areas	Time-weighted Values at all Depths in all Areas
		West	Central	Eastern		
First 222 days	Shallow	0·013	0·006	0·002	0·007	
	Middle	0·242	0·344	0·015	0·151	
	Deep	0·180	0·099	0·007	0·067	
Area mean values		0·046	0·044	0·003	0·030	0·049
Second 170 days	Shallow	0·013	0·013	0·014	0·013	
	Middle	0·049	0·208	0·369	0·151	
	Deep	0·078	0·093	0·014	0·047	
Area mean values		0·022	0·040	0·030	0·031	0·066
Third 161 days	Shallow	0·001	0·023	0·025	0·014	
	Middle	0·026	0·279	0·143	0·133	
	Deep	0·001	0·135	0·040	0·054	
Area mean values		0·003	0·059	0·039	0·032	0·062
All areas, all depths, all seasons						0·054

The values of F are subject also to a reservation with respect to the values for A which, in Table 16, are chart estimates only: that is, the areas of which they are a measure are simply the spaces between arbitrarily chosen depth contours, and may be not the boundaries of distribution of the species caught. We know that the stocks occupy a part of the Bight significantly greater than the relatively small proportion represented by the blocks (Table 8) in which the catches analysed here were made; this evidence comes from fishing in other blocks by the *Southern Endeavour* and other vessels. For stock estimate purposes we should consider three areas: first, total continental shelf area (to which possibly some slope area should be added); second, a "range" over which the stocks may move, almost certainly smaller than the first; third, "fishing grounds", which may be smaller than the second, either because of nature of bottom (e.g. presence of rough bottom on which a trawl cannot be operated) or because the fish are differentially distributed, in either permanent or seasonally variable patterns, over the range. The total Bight area is approximately 54,000 sq. miles as shown in Table 1. The grounds fished by the *Southern Endeavour*, and with which this paper deals cover an area of about 7600 sq. miles, a large proportion of which (as shown by Table 9(*a*)) is of depth less than 81 fm. We have taken the 7600 sq. miles to be the range occupied by the species taken by the *Southern Endeavour*, but the total range in the Bight is certainly greater than this since the species have been taken in blocks other than those that make up this area. Although, as discussed in Section V, the *Southern Endeavour* data give some evidence of patterns of distribution, including migratory effects, this evidence is insufficient to permit a distinction between "range" and "fishing grounds". On the east coast the fishing grounds, with area of 3700 sq. nautical miles, constitute 27% of the total shelf area; for what it is worth, this percentage may be contrasted with the proportion, 13%, which our minimum estimate of stock range in the Bight is of total shelf area there.

On the basis of the above considerations we consider that the values of F in Table 32 probably give a reasonable representation of the relative intensity of fishing by the *Southern Endeavour*, as between the various time–space cells. Each value however is too great, because of the assumption that q has value 1; to take a value

TABLE 33

SPECIES DENSITY PER SQUARE MILE IN GREAT AUSTRALIAN BIGHT

Fishery	Mean Cell* Value (lb)	Range of Cell Values (lb)
Bight Redfish	1252	308–2870
Flathead	224	43–856
Jackass fish	1120	374–4728
Miscellaneous	1338	220–2972

* This refers to the cells of Table 19

of 0·5 would be more realistic and would mean halving the values in Table 32. The values in the right-hand column of Table 32 are period and entire operation values adjusted to annual rates; halving these suggests an overall annual value for F of about 0·03. Similar calculations with respect to vessels on the east coast (which used a similar net) gave a value of $F = 0 \cdot 14$ for three trawlers operating in 1915–18, and values up to 1·77 (83% exploitation per annum) in the years of heaviest fishing.

For the *Southern Endeavour* $F = 0 \cdot 03$ signifies an *average* population biomass, of the fishable stocks of the species taken by the *Southern Endeavour*, of about 30,000,000 lb, or an average stock density of about 4000 lb per sq. nautical mile. Calculation of stock biomass for each species separately, in each time–space cell, from the simple form of equation (9), $\overline{P} = C/F$, leads to the same result, and the following values for the species.

The values in Table 33 must be treated with caution; they are subject to the variability summarized in Table 19 and to the disabilities discussed above with regard to the values of $p(= a/A)$ and $q(= n/N)$, where N is the number of fish in the path of a trawl and n is the number of these which are caught.

VII. Discussion

The first result of the analysis reported here is that it shows the *Southern Endeavour* to have confirmed, what had been demonstrated by *Endeavour* and other vessels, that substantial stocks of Bight redfish, flathead, jackass fish, and miscellaneous species inhabit the Great Australian Bight. It also confirmed and extended knowlege with regard to the following points:

(1) Location and general extent of the grounds occupied by these stocks;

(2) Composition of the stocks;

(3) Seasonal patterns of distribution and composition of the stocks.

Analysis of the data with respect to individual hauls has added precision to the account of these features and some quantification of them. From these results it appears that the stock is of very useful proportions, probably at least as large as that on the east coast grounds, and with similar densities.

These results may appear to be at variance with the fact that financially the *Southern Endeavour*'s operations proved unsatisfactory. Whilst insisting that the resources information from such operations should be dealt with, and assessed in their own right, as has been done in this paper we can also point out that to argue to resources from the financial results of any fishing enterprise can be erroneous for many reasons which, however, we can consider under two headings; first as to costs and earnings, second as to vessel performance.

With regard to the first it is sufficient to point out that the system that determines the costs of fishing and the prices received for the catch operates independently of that which determines the abundance and distribution of fish. Some fishing units succeed (financially) on poor grounds whilst others fail on rich grounds; of two fishing units operating alongside one another, one may fail and the other succeed. Under this heading we may also note that a lone fishing unit suffers considerable disadvantages with respect to in-port facilities and disposal of catch.

With regard to vessel performance we have first to point out that this can be reliably assessed only by the comparison of results of vessels fishing a common ground; only limited comparison could be made of *Southern Endeavour*'s operations, and not much can be made of the comparison. However, we must also draw attention to the lower catch (as rate and total) in the third period of *Southern Endeavour*'s work in contrast with that of the first period and point out that the operations of the third period differed from that of the first period in that

(1) much of the first-period fishing was in the central and western areas, whereas that of the third period was largely in the eastern and central areas;

(2) gear was changed in the second period;

(3) the hauls were on the average longer in the third period;

(4) there were more failed hauls in the third period.

The results of earlier sections (VI(*b*) and (*c*) (i)) of this paper show that differences (1), (2), and (3) above would have caused a lowering of catch; cause (4), which perhaps reflected a running-down of gear, obviously would have reduced the performance.

The *Southern Endeavour*'s recorded catch rates were lower than actual because of rejection at sea and of non-record (see Sections III(*c*), V(*b*), and VI(*c*)(ii)). The actual rates were probably lower, than they might have been, because *inter alia* of the difference between the third and first periods, discussed above. The performance overall was lower because of operational difficulties which caused much lost time, as discussed in Section IV(*b*)(iii). Nevertheless, her results were (as discussed in Section VI(*d*)) similar to those of the *Endeavour*, *Commiles*, and *Ben Dearg* in the Bight, to those of the *Endeavour* on the coast east of Australia, to those of commercial vessels over many years of commercial exploitation of the east coast grounds, and of other vessels on grounds in other parts of the world.

An important feature of this work has been the difficulty introduced by the uneven distribution of effort as a consequence of which certain important questions remain unanswered. The data suggest that although a planning of the work to give even distribution of effort might have reduced the catch taken by nearly 20%, to have done so would certainly have reduced considerably the doubt that surrounds some matters discussed in this paper.

VIII. Acknowledgment

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