ESTIMATION OF FISHING EFFORT IN THE WESTERN NORTH ATLANTIC FROM AERIAL SEARCH DATA

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ABSTRACT

Three estimators of days fished were developed from aerial search data obtained by fisheries surveillance operations over the northwest Atlantic off the northeast coast of the United States. These algorithms estimate fishing effort by applying functions of past aerial observations and past reported effort to aerial data from the time period for which effort is to be calculated. An estimator based on the relation of the average number of fishing vessels that were observed per flight and days fished as reported has produced easily calculated estimates of days fished to within ±0.50 of the reported value in 90% of all cases, 1971-73. An estimator based on the probability of a day fished if not sighted by fisheries surveillance operations provided an estimate of fishing effort to within ±0.50 in 95% of all cases. An algorithm based on the probability of a day on fishing grounds, if not actually observed, and on the ratio of days fished to days on grounds enabled the calculation of days fished with largest error (within ±0.50 in approximately 80% of all cases).

Prior to 1961, the waters off the northeast coast of the United States were fished exclusively by the domestic fleet. However, in 1961 distant water fishing fleets of other nations began fishing this area. Concern for the presence of these fishing vessels prompted the United States to observe and record the activities and magnitude of such fleets. These observations over the 160,000 km^2 fishing grounds were made from land-based aircraft; one to several flights were made each month. Although fisheries statistics are reported by fishing nations, such statistics are only available at least 6 mo after the close of the reporting period. Overflight observations are therefore the only available up-to-date information on that fishery.

The fishery in these waters is regulated by the International Commission for the Northwest Atlantic Fisheries (ICNAF), a fisheries management directed treaty organization. Under the objective of maintaining a maximum sustained catch, the Commission sets regulations "to achieve the optimum utilization of the stocks of those species of fish which support international fisheries in the convention area."[2] Intensive fisheries harvest regulations by that agency[3] have required progressively larger cutbacks in fishing by fleets other than the United States and Canada in these waters. (ICNAF Statistical Subareas 5 and 6, Figure 1.)

The United States has expressed its concern to ICNAF as to adherence to these fisheries regulations in 1974.[4] This concern originated from preliminary examination of the fisheries overflight data.

As a consequence, stochastic methods to monitor the fishery through the analysis of overflight data are of chief importance. In response to such needs three estimators of fishing effort are presented. These estimators of days fished are based on the aerial surveillance data and concomitant reported fishing effort. (Fishing effort as reported by each ICNAF member nation is published annually, usually about 1 yr following the reporting period. Such statistics used in this study were obtained from the ICNAF Statistical Bulletin, Vol. 19-23, Dartmouth, N.S.) In each estimation method, functions developed from aerial surveillance and reported data in a previous time interval are used to calculate fishing effort during a future time interval for which only aerial surveillance data are available.

METHOD

Fisheries surveillance flights were approximately 12 h or less in duration and were carried out

[1]Northeast Fisheries Center, National Marine Fisheries Service, NOAA, Woods Hole, MA 02543.

[2]ICNAF. 1974. ICNAF Handbook. Dartmouth, N.S., Can., 78 p.

[3]ICNAF. 1974. Proceedings of the third special meeting, October, 1973, N.S., Can., 34 p.

[4]ICNAF. 1975. Proceedings of the fifth special meeting, November, 1974, N.S., Can., 40 p.

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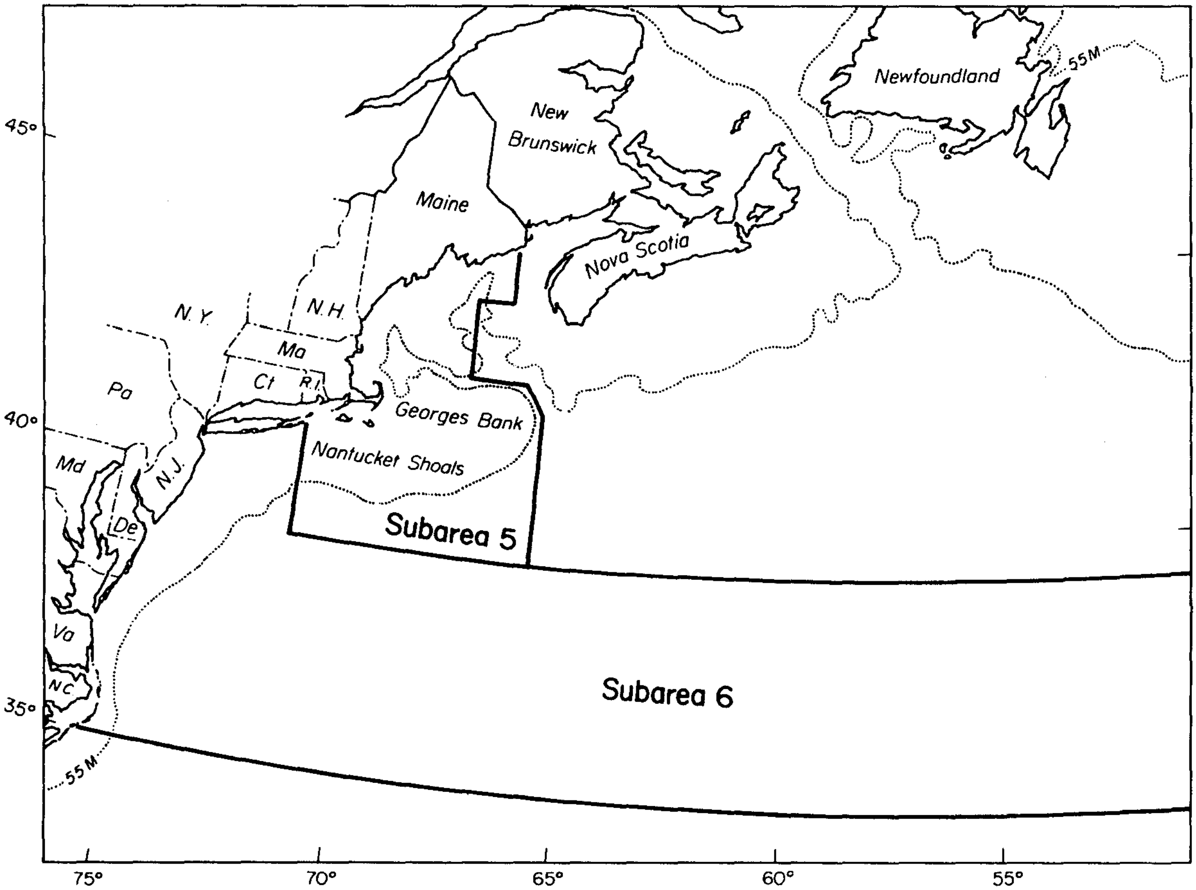

FIGURE 1.–ICNAF Subareas 5 and 6.

during daylight hours. The primary objective of each of the flights was to observe as many vessels as possible. (U.S. and Canadian vessels were not considered to be of major concern and therefore were not sought out.) Flight paths were therefore not set as required by a probability sampling scheme; rather, a searching technique was employed. Flights were first directed to areas of likely fleet concentration. Such areas were determined from seasonal fleet locations observed on overflights in preceding years and the reports of current fleet locations by U.S. fishers. In the event that major fleet concentrations were not encountered at the expected location or on the way to it, the area was searched as extensively as the range of the aircraft would permit.

During late winter and early spring these distant-water fishing fleets were concentrated from off New Jersey southward, so that fishing surveillance operations based in Virginia covered these fishing grounds. In late spring, the fleets moved northward to fishing grounds off New Jersey and New York, and flight paths were directed to those areas. During the summer and fall, surveillance flights originating on Cape Cod, Mass., monitored fishing areas on Georges Bank, Nantucket Shoals, and, to some extent, areas in the Gulf of Maine. The fleets moved southward with winter so that fisheries surveillance again became concentrated in areas off New York and New Jersey.

Upon encountering a cluster of fishing vessels, fisheries surveillance agents recorded the hull identification number, name, and nationality of each vessel. Other information including the fishing gear in use and operational mode (i.e., engaged in fishing operations or in other activities) at the time of sighting was also recorded. Vessels were judged to be fishing if any evidence was apparent that fishing had occurred on that day. Since ICNAF defines a day fished as a day in which any fishing occurred, an observation of a vessel fishing was logically defined as an observed day fished. Although the majority of vessels sighted were in some phase of fishing operations, some vessels were observed to be in other operational modes such as drifting, steaming, anchored, loading, unloading, or jogging in heavy seas.

These observations therefore allowed certain fishing effort variables to be derived by nationality and gear type. They include: 1) the number of times any vessel was observed on the grounds (i.e., observed days on grounds), 2) the number of times those same vessels were observed fishing (i.e., observed days fished), and 3) the number of vessels.

These overflight data were subject to limitations which were accounted for in the analysis. First, some observed vessel days have probably been incorrectly categorized. Surveillance flights usually occurred before midday; consequently a sighted vessel that did not fish until late in the day was recorded as not fishing. Such an event was therefore interpreted in the analysis as an observed day on grounds but not as an observed day fished as would have actually been the case. This limitation, as will be explained later, has little effect on the estimation of days fished if such inaccuracies are constant in magnitude through time. These data were further limited in that incorrect vessel identifications sometimes occurred. Adverse weather conditions, dense fleet concentrations, hull scripts of poor visibility, and inaccurate interpretations of non-Roman script resulted in the recording of incorrect individual vessel identifications. Lists received from certain countries (Japan, Romania, Spain) made possible the verification of hull scripts observed during 1974. The comparison of these reported hull identifications with those recorded on overflights during 1974 determined that individual vessel identifications recorded two or more times on fisheries surveillance operations were almost always correct; those recorded only once were almost always incorrect. For example, 40 Spanish stern trawlers were in ICNAF Subarea 5 and Subarea 6 (Figure 1) during the first 10 mo of 1974[5]. During that period, 39 separate Spanish stern trawlers were recorded on fisheries surveillance activities more than once. The number of vessels in the area during a time period of interest was therefore established by considering only vessel identifications observed by fisheries surveillance personnel more than once over the period 1965-74.

Knowledge of each country's fishing effort, both total and by types of gear used, and of the total effort expended by all countries, is of prime concern in existing fisheries management regimes. Separate estimates were therefore made for each country and vessel-type, as were estimates of each country's total effort and estimates for each of the total stern trawl and total side trawl fleets.

In addition it was hypothesized that the relation between reported and observed effort for the various gear and nationality components could be different. Stern trawlers are larger and were expected to be of greater visibility than smaller vessels. Also, surveillance searching operations were likely directed towards certain national fleets as a result of their greater size, their presence in an area closed to fishing, or because their catches were of particular immediate concern. If such relationships are different, separate estimates of functions of sighted and reported effort for each fleet component would logically increase estimation accuracy.

Estimator I

The ratio of reported days fished to the average number of sighted days on grounds per flight were easily computed for time periods when reported fishing effort was available:

$$R = f/\bar{g}' \qquad (1.1)$$

where $$\bar{g}' = \left(\sum_{i=1}^{A} g_i' \right) \div A,$$

A = the number of flights made during the time period,

g_i' = the number of sighted days on grounds during the ith flight, and

f = the number of days fished during the time period as reported to ICNAF.

This ratio may then be applied to aerial observations in some future time period to estimate days fished before the value is reported:

$$\hat{f} = R \cdot \bar{g}'. \qquad (1.2)$$

R is computed from previous data and $\bar{g}'$ is cal-

[5]ICNAF. 1974. Comments of the Spanish delegation on the U.S. memorandum annexed to ICNAF Comm. Doc. 74/41. Special Meeting ICNAF Comm. Doc. 74/44, Ser. No. 3422.

culated from overflight data from the time period for which the estimate is to be made.

Estimator II

Days on grounds reported to ICNAF (g) were correlated with observed days on grounds (g') and fleet size (V) as established from aerial surveillance data to estimate the probability of a day on grounds that was not sighted [$P(G/N)$] for any desired time period (Δt):

$$P(G/N) = (g - g') \div ((V \cdot \Delta t) - g'). \qquad (2.1)$$

(See Appendix for the derivation of this probability and for the resulting estimator for days fished.) In addition, the relation between days fished (f) and days on grounds (g) may also be established from reported effort:

$$K = f \div g. \qquad (2.2)$$

Fishing effort may then be estimated for some future time period from overflight data by assuming the K and $Pr(G/N)$ previously established:

$$\hat{f} = K\,[P(G/N) \cdot (V \cdot \Delta t - g') + g']. \qquad (2.3)$$

Estimator III

The probability of a day fished if not observed [$P(F/N)$] may be computed for any time period (Δt) for which reported days fished (f), the number of vessels present (V, as determined from vessel identification numbers observed on overflights), observed days on grounds (g'), and observed days fished (f') are available:

$$P(F/N) = (f - f')/((\mathrm{V} \cdot \Delta t) - g'). \qquad (3.1)$$

(See Appendix for derivation of this probability and of the resulting estimator.) If this computed probability is assumed for some future time period for which reported effort is not available, days fished for that time period may be estimated:

$$\hat{f} = P(F/N) \cdot ((\Delta t \cdot V) - g') + f'. \qquad (3.2)$$

In order to develop this algorithm, it was assumed that a vessel did not fish at all during the day it was sighted if it was observed in the nonfishing mode. Since surveillance flights were usually completed before afternoon, it is possible, as noted earlier, that evidence of fishing was not observable if the vessel did not fish until late in the day so that the above assumption may have been violated in some cases. If this occurred the $P(F/N)$ is incorrectly calculated, a situation having no effect on the estimates of days fished if such inaccuracies are constant from one time period to another. Since vessels are usually engaged in fishing operations whenever sea conditions permit, such inaccuracies can occur only during days when sea conditions disallow fishing during morning hours (when surveillance flights usually occur) and permit fishing later during the day. If the frequency of such weather conditions are assumed to be constant the magnitude of these inaccuracies may also be expected to be unvarying.

RESULTS

Reported effort and aerial observation data from 1969-73 (Table 1) were used in the various equations to compute R(estimator I), $P(G/N)$(estimator II), K(estimator II), and $P(F/N)$(estimator III). The number of surveillance flights (A, Equation 1.1) is required to calculate R. The numbers of flights for 1969-73 were 64, 66, 91, 105, and 109, respectively. The $P(F/N)$ and R were computed for each gear-country category, for each country, and for all stern trawlers and all side trawlers for each year, 1969-73 (Table 2). Since days on grounds were not consistently reported except by the German Democratic Republic (GDR) and in fact were never reported by some countries, K and $P(G/N)$ could not be calculated in many cases.

The variables R, $P(F/N)$, and $P(G/N)$ exhibit no trends of increase or decline through the years examined; however, these values varied, at times substantially, from year to year. Therefore, in order to decrease estimation error, these variables were averaged whenever possible over years preceding the year for which the estimate was made. The average value was then used to make the estimate. These variables for 1969-72 were averaged to make the 1973 estimates; 1969-71 were averaged to make the 1972 estimates; 1969 and 1970 were averaged to make the 1971 estimates; and the 1969 values were used to make the 1970 estimates.

As stated above, days on grounds were infrequently reported so that such sequential averaging of the $P(G/N)$(estimator II) was not possible except in the case of the GDR. The Union of Soviet

TABLE 1.—Reported days fished (f), reported days on grounds (g), observed days fished (f'), observed days on grounds (g'), and fleet size (v), 1969-73.

Country and gear	1969					1970					1971				
	f	g	f'	g'	v	f	g	f'	g'	v	f	g	f'	g'	v
USSR															
Total	35,922	45,391	2,623	2,901	518	23,856	—	2,167	2,478	434	26,673	—	3,049	3,726	511
Side trawl	26,518	32,527	1,987	2,130	401	20,173	—	1,757	1,982	331	17,468	—	1,891	2,356	332
Stern trawl	7,342	9,476	528	610	106	2,972	—	392	452	90	7,880	—	1,095	1,279	172
Purse seine	2,024	3,349	41	82	11	676	—	17	24	13	710	—	17	40	7
Not known	38	39	67	79	—	35	—	1	20	—	615	—	46	51	—
Poland	—	—	—	—	—										
Total	6,880	10,679	448	491	75	9,346	—	646	768	82	10,599	—	966	1,221	98
Side trawl	5,738	9,032	332	366	52	6,339	—	430	507	54	5,852	—	498	619	56
Stern trawl	1,142	1,647	116	125	23	3,007	—	216	261	28	4,747	—	441	558	42
Not known	—	—	—	—	—	—	—	—	—	—	—	—	27	44	—
GDR[1]															
Total	3,750	4,075	249	289	65	2,096	2,723	200	237	48	3,619	4,297	429	511	53
Side trawl	787	848	57	61	22	778	1,022	87	98	21	1,950	2,457	265	304	24
Stern trawl	2,963	3,227	192	228	43	1,318	1,701	113	139	27	1,669	1,840	156	198	29
Not known	—	—	—	—	—	—	—	—	—	—	—	—	8	9	—
FRG[2]															
Stern trawl	1,929	—	127	102	31	2,093	—	166	205	30	1,285	—	75	128	17
Japan															
Stern trawl	1,233	—	37	41	11	1,097	—	89	99	16	1,535	—	70	78	18
Spain															
Total	—	—	—	—	—	—	—	—	—	—	909	—	102	116	24
Stern trawl	—	—	—	—	—	—	—	—	—	—	410	—	17	21	6
Paired trawl	989	1,247	91	91	18	464	—	61	81	29	499	—	85	95	18
Bulgaria															
Stern trawl	145	—	4	6	2	217	—	13	17	4	1,261	—	111	147	13
Romania															
Stern trawl	51	55	2	3	1	195	—	4	11	4	438	—	47	50	8
TOTAL															
Side trawl	33,043	—	2,565	2,557	475	27,290	—	2,274	2,587	406	25,270	—	2,654	3,279	412
Stern trawl	14,805	—	1,014	1,183	217	10,899	—	1,002	1,200	205	19,225	—	2,012	2,459	305

Country and gear	1972					1973				
	f	g	f'	g'	v	f	g	f'	g'	v
USSR										
Total	29,492	39,631	2,264	3,263	498	20,948	29,049	1,147	2,024	392
Side trawl	17,307	22,753	1,214	1,725	278	9,244	13,594	276	601	168
Stern trawl	8,680	10,986	1,016	1,341	197	7,630	10,134	734	1,039	200
Purse seine	2,727	4,629	23	133	23	4,074	5,321	133	344	24
Not known	778	1,263	11	64	—	—	742	4	40	—
Poland										
Total	10,000	—	754	973	104	6,036	—	358	589	84
Side trawl	5,058	—	380	451	58	1,733	—	67	93	23
Stern trawl	4,942	—	371	518	46	4,303	—	283	484	61
Not known	—	—	3	4	—	—	—	8	12	—
GDR[1]										
Total	4,954	5,675	543	656	55	4,220	4,642	285	362	60
Side trawl	1,825	2,361	242	284	23	1,427	1,651	121	151	26
Stern trawl	3,129	3,314	300	360	32	2,793	2,991	164	209	34
Not known	—	—	1	12	—	—	—	0	2	—
FRG[2]										
Stern trawl	1,020	—	99	121	15	859	—	55	68	18
Japan										
Stern trawl	1,787	1,821	64	76	14	2,274	—	112	145	17
Spain										
Total	1,552	1,828	102	114	32	2,405	2,595	201	222	60
Stern trawl	1,017	1,194	27	30	6	2,024	2,106	94	107	25
Paired trawl	535	634	75	84	26	381	489	107	115	35
Bulgaria										
Stern trawl	1,325	—	134	189	14	993	—	43	70	12
Romania										
Stern trawl	305	—	15	22	7	333	389	19	25	7
TOTAL										
Side trawl	24,190	—	1,913	2,543	359	12,450	—	516	913	238
Stern trawl	22,205	—	2,026	2,657	331	21,209	—	1,504	2,147	374

[1]GDR = German Democratic Republic.
[2]FRG = Federal Republic of Germany.

TABLE 2.—Estimation parameters for Equations 1.2, 2.3, and 3.2.

Country		Stern trawl					Side trawl				
		1969	1970	1971	1972	1973	1969	1970	1971	1972	1973
USSR	$P(F/N)$	0.18	0.08	0.11	0.11	0.10	0.17	0.16	0.13	0.16	0.15
	$P(G/N)$	0.23			0.14	0.13	0.21			0.21	0.21
	R	770.30	434.00	560.70	679.60	800.50	796.80	671.80	674.70	1,053.50	1,676.50
	K	0.77			0.79	0.75	0.82			0.76	0.68
Poland	$P(F/N)$	0.12	0.28	0.29	0.28	0.18	0.29	0.31	0.27	0.23	0.20
	$P(G/N)$	0.18					0.47				
	R	584.70	760.40	774.20	1,001.80	969.10	1,003.40	825.20	860.30	1,177.60	2,031.20
	K	0.69					0.64				
GDR[1]	$P(F/N)$	0.18	0.12	0.15	0.25	0.22	0.09	0.09	0.20	0.19	0.14
	$P(G/N)$	0.20	0.16	0.16	0.26	0.23	0.10	0.12	0.25	0.25	0.16
	R	831.70	625.80	767.10	912.60	1,456.60	825.70	524.00	583.70	674.70	1,030.10
	K	0.92	0.77	0.91	0.94	0.93	0.93	0.76	0.79	0.77	0.86
Spain	$P(F/N)$			0.18	0.46	0.21	[2]0.14	[2]0.04	[2]0.07	[2]0.05	[2]0.07
	$P(G/N)$				0.54	0.22	[2]0.18			[2]0.06	[2]0.03
	R				1,776.70	2,061.80	[2]781.40	[2]850.70	[2]825.60	[2]668.80	[2]851.10
	K				0.95	0.96	[2]0.79			[2]0.84	[2]0.78
Japan	$P(F/N)$	0.30	0.18	0.23	0.34	0.36					
	$P(G/N)$				0.35						
	R	1,924.70	731.30	1,790.80	2,468.90	1,709.40					
	K				0.98						
Bulgaria	$P(F/N)$	0.19	0.14	0.25	0.24	0.21					
	R	1,546.70	842.50	780.60	736.10	1,546.20					
FRG[3]	$P(F/N)$	0.16	0.18	0.20	0.17	0.12					
	R	762.10	673.80	913.60	885.10	1,376.90					
Romania	$P(F/N)$	0.14	0.13	0.14	0.11	0.12					
	$P(G/N)$	0.14									
	R	1,088.00	1,170.00	797.20	1,455.70	1,451.90					
	K	0.93				0.86					
Total	$P(F/N)$	0.18	0.13	0.16	0.17	0.14	0.18	0.17	0.15	0.17	0.14
	R	800.90	598.10	711.50	877.50	1,076.70	827.00	696.20	701.30	998.80	1,486.40

Country		Purse seine					Total of all gears				
		1969	1970	1971	1972	1973	1969	1970	1971	1972	1973
USSR	$P(F/N)$	0.50	0.14	0.28	0.31	0.47	0.18	0.14	0.13	0.15	0.14
	$P(G/N)$	0.83			0.54	0.59	0.23			0.20	0.19
	R	1,579.70	1,859.00	1,615.30	1,076.40	2,152.90	792.50	635.40	636.40	949.00	1,128.10
	K	0.60			0.59	0.77	0.79			0.74	0.72
Poland	$P(F/N)$						0.24	0.30	0.28	0.25	0.17
	$P(G/N)$						0.38				
	R						896.80	803.20	789.90	1,079.10	1,117.00
	K						0.64				
GDR[1]	$P(F/N)$						0.15	0.11	0.17	0.23	0.18
	$P(G/N)$						0.16	0.14	0.20	0.26	0.20
	R						673.40	583.70	644.50	792.90	1,270.70
	K						0.92	0.77	0.84	0.87	0.91
Spain	$P(F/N)$						0.14	0.04	0.06	0.05	0.02
	$P(G/N)$						0.18			0.15	0.11
	R						781.40	397.70	713.10	1,429.50	1,180.00
	K						0.79			0.85	0.93
Japan	$P(F/N)$						0.30	0.18	0.23	0.34	0.36
	$P(G/N)$									0.35	
	R						1,924.70	731.30	179.80	2,468.90	1,709.40
	K									0.98	
Bulgaria	$P(F/N)$						0.19	0.14	0.25	0.24	0.21
	R						1,546.70	842.50	780.60	736.10	1,546.20
FRG[3]	$P(F/N)$						0.16	0.18	0.20	0.17	0.12
	R						762.10	673.80	913.60	885.10	1,376.90
Romania	$P(F/N)$						0.14	0.13	0.14	0.11	0.12
	$P(G/N)$						0.14				0.14
	R						1,088.00	1,170.00	797.20	1,455.70	1,451.90
	K						0.93				0.86
Total	$P(F/N)$										
	R										

[1]GDR = German Democratic Republic.
[2]Paired trawl.
[3]FRG = Federal Republic of Germany.

Socialist Republics (USSR) reported days on grounds in 1969 and 1972 only, so that estimates for 1970-72 were based on calculations of $P(G/N)$ and K from 1969 data. The 1973 estimate was based on the average of the 1969 and 1972 values. Spanish paired trawl days on grounds were reported in these same years so that calculations via estimator II were achieved in the same way as for the USSR. Spanish stern trawl and Japanese days on grounds were first reported in 1972 so that the 1973 calculation of days fished by estimator II was based on the 1972 data only. Poland and Romania reported days on grounds in 1969 only, so that all calculations by estimator II were based on $P(G/N)$ and K values computed from 1969 data.

Estimates of days fished were then made for each country-gear partition, for each country's total effort, and for all stern trawlers combined and all side trawlers combined (Table 3). Estimator II was not used to estimate effort for Bulgaria, the Federal Republic of Germany (FRG), Japan for 1970 and 1971, and Spanish stern trawlers in 1972 because of the absence of reported days on grounds which is required by the estimator.

A coefficient of estimation error was calculated to establish a measure of estimator performance:

$$\epsilon = (\hat{f} - f)/f. \qquad (4.0)$$

This error coefficient, then, is the difference between the estimated days fished ($\hat{f}$) and the reported days fished (f) expressed as a proportion of the reported value. An error coefficient was computed for each estimate made and these coefficients (Table 4) were then evaluated to establish the results of partitioning, to compare the relative abilities of the three estimators, and to establish estimator dependability.

Inspection of error coefficients indicated that they decreased considerably (especially those of estimators II and III) after 1970, likely as a result of the averaging of estimation parameters. Since the error coefficients then tended to stabilize, only values of ϵ for the 1971-73 period were used to analyze estimator performance.

The frequency distribution of ϵ for estimator II is slightly negatively skewed, a characteristic also exhibited by the distribution of ϵ for estimator III (Figure 2). This indicates a positive bias in both estimators (approximately 10% in each case). Each of these two distributions is also noticeably leptokurtic indicating a marked clustering of error coefficients in the interval ± 0.10. The distribution of ϵ for estimator I appears to be approximately symmetrical and without the pronounced peakedness exhibited by the other two. Statistics were computed from the calculated error coefficients to establish the probability that the ϵ came from normal distributions. (These statistics, a and b_1, and tables of their probabilities are given by Pearson and Hartley 1956:61-62, 183.) In the case of the error coefficients of estimators II and III, the probability that the error coefficients come from normal distributions is extremely remote,

TABLE 3.—Estimated days fished calculated by three different algorithms.

	1970 Estimate			1971 Estimate			1972 Estimate			1973 Estimate		
	I	II	III	I	II	III	I	II	III	I	II	III
USSR	29,754	30,069	30,063	29,234	35,896	30,410	21,384	34,848	29,293	13,988	25,635	22,488
Side trawl	23,928	22,156	21,970	19,010	22,462	21,200	11,737	18,696	16,417	4,406	10,184	9,627
Stern trawl	5,275	6,156	6,188	8,462	12,009	9,041	7,375	13,717	9,712	5,825	11,321	9,312
Purse seine	574	2,367	2,397	756	2,367	827	2,134	4,209	2,561	5,684	3,617	2,754
Poland	10,435	7,565	7,624	11,405	9,162	8,485	7,691	9,620	10,846	4,821	7,671	8,369
Side trawl	7,708	6,047	6,007	6,219	6,303	6,172	3,850	6,986	6,393	825	2,533	2,336
Stern trawl	2,312	1,233	1,452	4,124	2,096	2,230	3,485	2,248	4,155	3,465	2,874	5,595
GDR[1]	2,418	2,786	2,792	3,530	2,608	2,877	3,960	3,312	3,326	2,237	3,894	3,839
Side trawl	1,226	786	7,567	2,254	941	1,037	1,743	1,243	1,278	903	1,432	1,468
Stern trawl	1,752	1,861	1,857	1,585	1,579	1,731	2,542	2,100	1,998	1,504	2,421	2,293
Spain							685		1,161	2,182	3,205	2,362
Paired trawl	912	1,526	1,513	615	994	661	395	1,737	201	635	1,363	1,027
Stern trawl	—	—	—	—	—	—	508		956	2,619	4,718	1,079
Japan	2,887		1,817	1,138		1,617	1,073		1,246	2,300	2,200	1,693
Bulgaria	398		294	1,930		884	1,902		1,098	627		934
FRG[2]	2,367		1,902	1,010		1,111	902		1,065	504		1,211
Romania	181	203	200	620	204	430	213	359	355	259	361	346
Total side trawl	32,418		28,424	27,444		28,500	17,959		23,600	6,750		15,086
Total stern trawl	14,563		14,255	18,903		18,886	17,802		20,541	14,714		23,002

[1]GDR = German Democratic Republic.
[2]FRG = Federal Republic of Germany.

TABLE 4.—Error coefficients of three estimates of days fished.

Country	Gear type	1970 Estimator I	1970 Estimator II	1970 Estimator III	1971 Estimator I	1971 Estimator II	1971 Estimator III	1972 Estimator I	1972 Estimator II	1972 Estimator III	1974 Estimator I	1974 Estimator II	1974 Estimator III
USSR	All	0.247	0.260	0.260	0.092	0.346	0.140	−0.275	0.182	−0.007	−0.332	0.223	0.074
	Side trawl	.186	.098	.089	.088	.286	.214	−.322	.080	−.051	−.523	.081	.041
	Stern trawl	.775	1.071	1.082	.074	.524	.147	−.150	.580	.119	.237	.484	.220
	Purse seine	−.151	2.502	2.546	.064	2.502	.164	−.217	.544	−.061	.395	.112	.324
Poland	All	.117	−.191	.184	.076	−.136	−.092	−.231	−.038	.085	−.201	.271	.387
	Side trawl	.216	−.046	.052	.063	.077	.026	−.239	.381	.264	−.524	.462	.348
	Stern trawl	−.231	−.107	−.517	−.131	−.558	−.259	−.295	−.545	−.195	−.195	−.332	.300
GDR[1]	All	.154	.329	.332	−.025	−.279	−.205	−.201	−.331	−.329	−.470	−.077	−.090
	Side trawl	.576	.011	.302	.156	−.052	−.468	−.045	−.319	−.300	−.360	.003	.029
	Stern trawl	.314	.412	.342	−.050	−.054	.037	−.187	−.329	−.361	−.462	−.133	−.179
Spain	All	.965	2.289	2.299				−.589		−.252	−.093	.333	−.018
	Side trawl				.233	.993	.327	−.263	.119	−.802	.664	2.578	1.697
	Stern trawl							−.050		.787	.244	1.331	−.467
Japan	All (stern trawl only)	1.632		.656	−.258		.053	−.400		−.303	.011	−.032	−.256
Bulgaria	All (stern trawl only)	.836		.355	.536		.299	.435		−.171	−.368		−.059
FRG[2]	All (stern trawl only)	.131		−.091	−.214		.136	−.115		.045	−.413		.410
Romania	All (stern trawl only)	−.070	.045	.027	.416	.045	−.017	−.306	.179	.166	−.223	.084	.038
All	Side trawl	−.188		.042	−.086		.128	.258		−.024	.458		.211
All	Stern trawl	−.339		.308	.017		−.018	.198		−.075	.306		.085

[1]GDR = German Democratic Republic.
[2]FRG = Federal Republic of Germany.

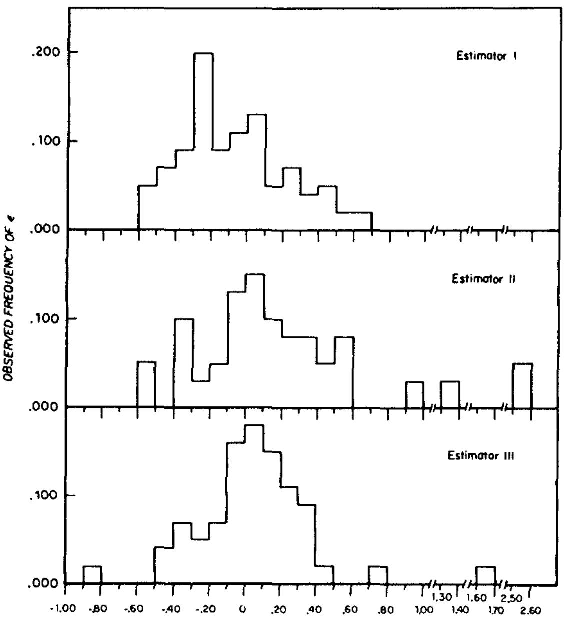

FIGURE 2.—Observed frequency of error coefficients (ε) of three estimators of days fished.

less than 0.01. In the case of error coefficients of estimator I, that probability is 0.05.

An analysis of variance for a one-way layout with unequal replication (Steel and Torrie 1960:112-114) was employed to investigate possible differences in the mean values of estimation error in regards to the kinds of category estimated. Here, a separate analysis was carried out for each of the three estimators. All error coefficients for estimates of total days fished by country, all gear types combined, were considered as a single group; error coefficients of estimates of days fished by each gear type (i.e., estimates of days fished by all side trawls and by all stern trawls) as another group; and error coefficients of estimates of days fished for gear-country categories as the final group. F-tests indicated a high probability (>0.25) that errors were the same among these groups in the cases of estimators I and III. Estimation of gear totals (i.e., total stern trawl and total side trawl) was not possible via estimator II because days on grounds were not reported for all countries. The analysis for estimator II therefore included two groups, i.e., gear-country categories and country totals. As before, the likelihood that error rates were the same among these two groups was high (>0.25).

Although application of the F-test requires that normality assumptions be made, the test is robust in regard to violations of these assumptions (Scheffé 1959:361-364) so that limited deviations from normality are likely to be of limited consequence. However, the nonparametric Kruskal-

Wallis one-way analysis of variance (Siegel 1956: 184-194) was also applied and indicated the same general results. The probability of obtaining the calculated test statistic under the hypothesis of no difference among these groups with respect to means is 0.553, 0.410, and 0.872 for estimators I, II, and III, respectively. Both parametric and nonparametric tests, then, indicate that the error rates of each estimator are of the same magnitude regardless of the kind of category estimated.

Analyses for possible differences in error coefficients among estimators were carried out in the same manner. All error coefficients of estimator I were considered as one group, of estimator II as another, and of estimator III as the third group. Both parametric analysis of variance and nonparametric techniques indicated that the different estimators probably produced different error coefficients. The likelihood of obtaining the calculated F statistic under the hypothesis of no difference among the groups is low (0.006). The Kruskal-Wallis analysis technique also indicated a low probability of obtaining the calculated statistic under that hypothesis (0.007).

Cumulative frequency distributions of the ϵ from 1971-73 estimates were used to compare estimator performances and to establish estimator dependability. These frequency distributions were established in the following way. Arbitrary bounds or intervals (μ) were set up so that the first bound included error coefficients from -0.049 to +0.049, the second from -0.099 to +0.099, and so on. The number of error coefficients from Table 4 falling in each interval was counted; these counts were then divided by the total number of coefficients calculated for that estimator to establish the percent of occurrences in each interval. These proportions were then interpreted to be the likelihood of the error coefficient occurring within each bound ($\Phi\mu$, Table 5). Graphs of these probabilities (Figure 3) indicate that estimator III is the most desirable. Its error coefficient is most likely to occur within set error bounds of $\pm$0.50 or less. For error bounds greater than $\pm$0.50, estimator I was superior. Estimator II was always inferior to estimator III, but for very narrow error bounds ($\pm$0.20 and less) estimator II was superior to estimator I.

Although estimator II produced the least desirable calculations of days fished, a like algorithm also based upon $P(G/N)$ estimated days on grounds acceptably well:

TABLE 5.—Frequency of error coefficients of estimates of days fished, 1971-73.

Interval of error		Frequency of occurence					
		Estimator I		Estimator II		Estimator III	
From $-\mu$	To $+\mu$	Nos.	Φ	Nos.	Φ	Nos.	Φ
0.049	0.049	4	0.073	4	0.103	10	0.182
.099	.099	14	.255	11	.282	20	.364
.149	.149	16	.291	15	.385	25	.455
.199	.199	21	.382	17	.436	31	.565
.249	.249	31	.564	18	.462	35	.636
.299	.299	36	.655	21	.538	40	.727
.349	.349	40	.727	26	.667	47	.855
.399	.399	43	.782	28	.718	49	.891
.449	.449	47	.855	28	.718	50	.909
.499	.499	50	.909	30	.769	52	.945
.549	.549	53	.964	33	.846	52	.945
.599	.599	54	.982	35	.898	52	.945
.649	.649	54	.982	35	.898	52	.945
.699	.699	55	1.000	35	.898	52	.945
.749	.749			35	.898	52	.945
.799	.799			35	.898	53	.964
.849	.849			35	.898	54	.983
.899	.899			35	.898	54	.983
.949	.949			35	.898	54	.983
.999	.999			36	.923	54	.983
1.049	1.049			37	.949	54	.983
1.699	1.699			37	.949	55	1.000
2.549	2.549			38	.974		
2.599	2.599			39	1.000		

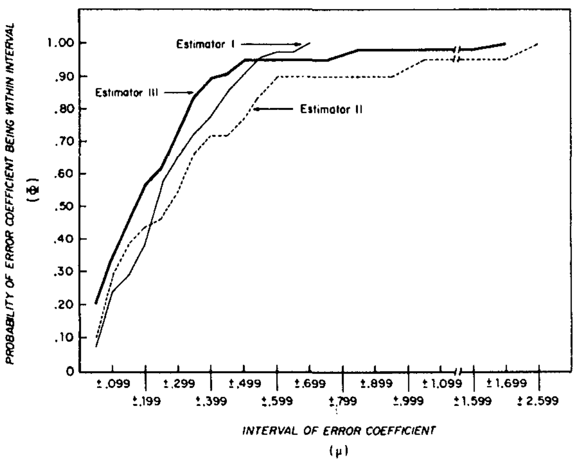

FIGURE 3.—Probabilities of error coefficients occurring within set bounds for three estimators of days fished.

$$\hat{g} = P(G/N)\,(V{\cdot}\Delta t - g') + g' \qquad (5.1)$$

where $\hat{g}$ is estimated days on grounds and other symbols are as before. Comparisons of calculated days on grounds to reported days on grounds were made when reported values were available (Table 6). These comparisons indicate that the error was less than $\pm$0.50 for 83% of such estimates.

Approximations of estimation dependability may be established from the calculations of

TABLE 6.—Reported and estimated days on grounds and estimation error rates.

		1970		1971		1972		1973	
		Estimate	Error	Estimate	Error	Estimate	Error	Estimate	Error
USSR	Total					43,998	11.0	32,449	11.7
	Side trawl					22,799	0.2	13,400	−1.4
	Stern trawl					17,768	62.5	14,337	41.5
	Purse seine					7,015	51.6	6,130	15.2
GDR	Total	3,028	11.2	3,387	−21.2	3,941	30.6	4,476	−3.6
	Side trawl	845	−17.2	1,238	−49.6	1,573	−33.4	1,859	12.6
	Stern trawl	2,023	18.9	2,051	11.5	2,308	−30.4	2,576	−13.9
Spain	Total							3,426	32.0
	Paired trawl					1,779	180.6	1,181	−43.9
	Stern trawl							6,937	1,318.6

probabilities of error ($\Phi\mu$, Table 5). The probability statement

$$Pr(-\mu < \epsilon < \mu) = \Phi\mu$$

defines these calculated values. Here, ϵ is the error coefficient (Equation 4.0), μ is an arbitrary limit of acceptable error, and $\Phi\mu$ is the likelihood of ϵ being within the interval $-\mu$ to $+\mu$. By substitution (i.e., $\epsilon = (\hat{f}-f)/f$) and reduction of terms:

$$Pr\left(\frac{\hat{f}}{1-\mu} > f > \frac{\hat{f}}{1-\mu} \right) = \Phi\mu.$$

Bounds on points estimates can therefore be calculated:

$$\text{upper limit} = \hat{f}.\ \frac{1}{1-\mu}$$

$$\text{lower limit} = \hat{f}.\ \frac{1}{1+\mu}$$

and values of $\Phi\mu$ from Table 5 can be used to approximate the likelihood that the reported days fished (f) will fall within the interval. For example, if estimator III calculated days fished to be 100, it may be stated that there is a 0.945 probability that the reported value of days fished is within the interval 67 to 200, i.e.,

$$Pr\left(\frac{100}{1-0.499} > f > \frac{100}{1+0.499}\right) = 0.945.$$

It is important to note, however, that the figures in Table 5 were computed directly from the frequency distributions of error rates of estimates made in the past (i.e., 1971-73). Therefore, estimation bounds may be correctly approximated on future point estimates only if it is assumed that future distributions of error coefficients are correctly represented by these past performance data.

DISCUSSION

Of the methods presented, estimator I (based on the ratio between days fished as reported and sighted days-on-grounds) and estimator III (based on the probability of a day fished given that it was not observed) exhibited the least error. Estimator III was consistently most accurate (especially in the last 2 yr) although the difference between the two is small. This estimator may be expected to calculate days fished to within $\pm$0.50 approximately 95% of the time. Estimator I has value in that it does not require sophisticated analysis of overflight data (only the numbers of sightings and numbers of flights are needed) and is less likely than other estimators to produce error coefficients greater than 0.50. It may be expected to produce estimates within $\pm$0.50, 90% of the time.

Estimator II, based on the probability of a day on grounds if it was not sighted, was consistently the poorest of the three. Its poor performance is likely the result of insufficient instances of reported days on grounds. These parameters allow computations of $P(G/N)$ and K, on which the estimate is based. In the case where complete data was available (GDR), effort was estimated very well by estimator II and, in fact, the error coefficient did not exceed 0.42. A similar estimator also based on $P(G/N)$, however, produced acceptable calculations of days on grounds for all countries that were within $\pm$0.50 of the reported value in approximately 80% of all cases.

Estimation error can result from sources which are known to have occurred in the past and are, therefore, of a magnitude predictable by the proposed methods for approximating probability limits on point estimates. The probabilities of fishing ($P(F) = f/(V \cdot \Delta t)$) from data in Table 1 were found to be highly correlated with the $P(F/N)$

(Table 2) as theoretically should occur. Therefore, when countries change fishing patterns from one time period to the next so that $P(F)$ differs, $P(F/N)$ also changes, thus introducing error in the estimates made by estimator III, a condition also true for $P(G)$ and $P(G/N)$ on which estimator II is based. This results from changes in the mean number of days fished (or days on grounds in the case of estimator II) per vessel, a likely occurrence if a particular fleet experiences difficulties in finding fish, if weather conditions are unusually unsuitable for fishing, or if equipment repair or modifications demand excessive lost time in a certain time period.

Although these changes theoretically should not produce changes in the ratio of reported to observed fishing effort (R, estimator I), other factors can conceivably produce such variation of that ratio. Changes in visibility due to weather can likely be an important factor. If fog or other visibility-restricting weather conditions are more prevalent in one time period than another, R may be expected to be larger during that period. Likewise, varying success of overflights in locating fleet concentrations is a factor. Unusually successful searching may be expected to produce ratios smaller than average while low success will tend to increase R.

In addition, changes in the accuracy of reported effort (f and g) will result in corresponding changes in the accuracy of calculations of $P(F/N)$, $P(G/N)$, R, and K for particular time periods. Since reporting accuracy cannot be measured, such deviations have been included in the error coefficients as have the above listed sources of error.

Although a method of calculating probability limits on estimates is presented, the methodology utilizes the observed past performance of each estimator to establish the probability of error. It must be assumed, therefore, that the frequency distribution of estimation error is correctly represented by these past data. Although this assumption can reasonably be made if fisheries surveillance flight patterns and fishing fleet movements are generally constant, caution should be exercised in this regard. If flight patterns or seasonal fleet movements change drastically, the probabilities of not sighting fishing effort (estimators II and III) and the ratio of reported to sighted effort (estimator I) will likewise change so that they are not correctly represented by the range of past values. Aberrant values will result if the fleets are extensively concentrated in different areas than in the past. Fleets will not be located by fisheries surveillance flights as well as in the past and, therefore, effort will not be observed to the same extent as in the past. As a result, values of $P(F/N)$, and R will be much greater than past values. Sizable underestimates of days fished will occur with probabilities greater than those represented by past error frequencies. Conversely, if fleet locations are anticipated by surveillance flight personnel much more accurately than in the past, these estimation constants will be much smaller than represented by past data, so that probabilities of overestimation will be much greater than represented by past performance data.

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APPENDIX

Estimators II and III are based on probabilities of not sighting daily units of fishing effort (i.e., vessel days which were on grounds or on grounds and fishing). These estimates require the calculation of these probabilities during some time period when reported days on grounds and days fished are available which can be correlated with sighted days on grounds, sighted days fished, and fleet size as determined from surveillance overflight data. These estimators were fashioned by considering the possible daily events, constructing the probability space in units of vessel days from reported and observed effort, and then deriving needed probabilities from the constructed space. Let the possible events be symbolized:

G = the daily event of a vessel on the grounds;
F = the daily event of a vessel on the grounds and fishing;
E = the daily event of a vessel not on the grounds, i.e., elsewhere;
S = the daily event of a unit of daily effort observed on overflights; and
N = the daily event of a unit of daily effort not observed on overflights.

Further, by defining the fleet size during some time period Δt, where t is in days, as the number of vessels that were present at some time during that period, the total event space (which is the sum of all possible events) is easily calculated:

$$n = V \cdot \Delta t$$

where n = the total number of all possible daily events,
Δt = the time period in days, and
V = the fleet size.

Even though certain cells in the event space (of little consequence to us) cannot be observed directly, the possible events defined in units of vessel days may be broken down:

Item	*Observed* (S)	*Not seen* (N)	*Total*
On the grounds (G)	g'	$g'' = g - g'$	g
Fishing (F)	f'	$f'' = f - f'$	f
Not fishing	$o' = g' - f''$	$o'' = o - o'$	$o = f - g$
Elsewhere (E)	e' = zero	e''	$e = n - g$
Total	g'	$n - g'$	n

From effort reported to ICNAF and from that observed on overflights, the number of daily events in each cell is easily defined. The number of events of vessel days fished (f) are reported to ICNAF and are either observed on overflights (f') or are not seen on overflights (f''). The number of events of vessel days on grounds (g) may be reported to ICNAF and are either observed on overflights (g') or not observed on overflights (g''). The event of a vessel day on grounds spent not fishing (o) is either observed (o') or not observed (o''). It is important to note that if a vessel day on grounds was fished but was observed on an overflight as not in the fishing mode, which may possibly occur if fishing operations were not initiated until late in the day after the flight occurred, that event would be incorrectly categorized as o' rather than as f'. The effect of this occurrence on estimator III will be discussed; it has no effect on estimator II. If a possible daily event were not on the grounds, then it was elsewhere (e) and was not observed (e''). It was not possible for a vessel day elsewhere to be observed; overflights were directed within the fishing grounds so that e' is zero in all cases. The numbers of daily events, then, are categorized as on the grounds (g) and fishing (f) or not fishing (o), or as elsewhere (e). The numbers of daily events in each category are symbolized by a single prime (′) if observed on overflights, as a double prime (″) if not observed, and without a symbol if the value is a total number of events.

Estimator II is best explained by considering the probability of a day on grounds:

$$^{6}P(G) = P(G,S) + P(G,N)$$
$$= P(G,S) + P(G/N) \cdot P(N).$$

From the above event space, the probabilities of on grounds and observed [$Pr(G,S)$], of on grounds if not observed [$\Pr(G/N)$], and of not observed [$P(N)$], are easily defined:

$$P(G,S) = g' \div n,$$
$$P(G/N) = g'' \div (n - g'), \text{ and}$$
$$P(N) = (n - g') \div n.$$

Then by substitution

$$P(G) = (g' \div n) + [(g - g') \div (n - g')] \cdot (n - g') \div n$$

[6]For an explanation of probabilities and the theorems used in the development of these expressions, see Hoel (1962:4-17).

which reduces to

$$P(G) = g \div n;$$

so that the equation may be solved for days on grounds:

$$g = n \cdot P(G).$$

Then by substitution

$$g = n[(g' \div n) + P(G/N) \cdot (n - g') \div n], \text{ or}$$
$$g = g' + P(G/N)\,(n - g').$$

Estimator II is then derived by inclusion of the ratio of days fished to days on grounds, $K = f \div g$, so that the above algorithm may be expressed in terms of days fished:

$$\hat{f} = K\,[g' + P(G/N) \cdot (n - g')].$$

An estimate of days fished ($\hat{f}$) may be made, then, from surveillance overflight data if calculations of R and $P(G/N)$ can be made from past data.

Estimator III is deduced from the event space according to the same rationale. The likelihood of an event of a vessel day fished expressed as observed and not observed is expanded to calculate days fished. From the event space it is apparent that:

$$P(F) = P(F, N) + P(F, S)$$

where $P(F)$ is the probability of a vessel day fished, $P(F, N)$ is the probability of a vessel day fished and not observed on overflights, and $P(F, S)$ is the probability of a vessel day fished and observed on overflights. Further, by application of the multiplication theorem of probabilities

$$P(F, N) = P(F/N) \cdot P(N)$$

where $P(F/N)$ is the probability of a vessel day fished given that it was not observed on overflights, and $P(N)$ is the probability that a possible vessel day (regardless of location or operational mode) was not observed on overflights. The first expression therefore can be written as

$$P(F) = P(F/N) \cdot P(N) + P(F, S).$$

Although all possible probabilities can be expressed in terms of the number of events in each category of the event space, those of interest are:

$$P(F, S) = f'/n,$$
$$P(N) = (n - g')/n, \text{ and}$$
$$P(F/N) = (f - f')/(n - g').$$

By substitution and reduction of terms

$$P(F) = f/n.$$

The number of vessel days fished, then, is the product of the entire event space and the probability of fishing, i.e.,

$$f = n \cdot P(F).$$

Then, by substitution, estimator III easily follows so that days fished are estimable from overflight data if $P(F/N)$ can be predetermined from past data:

$$\hat{f} = f' + P(F/N) \cdot (n - g').$$

From possible algorithms derivable from the event space, this form makes most use of overflight data and is least dependent on functions calculated from past data.