

ANALYSIS OF THE CORRELATION AMONG INDICES OF RELATIVE ABUNDANCE
OF TUNA AND BILLFISH SPECIES CAUGHT IN THE TAIWANESE AND
JAPANESE ATLANTIC LONGLINE FISHERIES

Nelson M. Ehrhardt¹

ABSTRACT

Catch per unit of fishing effort is widely used in stock assessment work either directly as an index of stock abundance in production modelling or as an index to calibrate cohort analyses. In longline fisheries this index represents not only relative abundance but also relative performance of the gear under a variety of operational and environmental conditions. Catch per effort information of the Japanese longline fishery in the Atlantic is extensive both in time and space; therefore, it represents a large data base for stock assessment purposes. It is not clear, however, if these data are representative of trends that might be observed in other longline fleets operating on the same stocks. In this paper spatio-temporal catch-per-hook of Atlantic large pelagics caught by the Japanese and Taiwanese longline fleets are analyzed using multivariate statistical techniques. The results show that CPUE is an index which is associated among some tuna species caught by the two fleets. However, the index may not be appropriate to characterize relative abundance of swordfish and billfishes.

RESUME

La prise par unité d'effort est largement utilisée dans les travaux d'évaluation des stocks, soit directement en tant qu'indice de l'abondance du stock dans le modèle de production, soit en tant qu'indice pour ajuster les analyses de cohortes. Dans les pêcheries de palangre, cet indice représente non seulement l'abondance relative, mais aussi la performance relative des engins selon toute une variété de conditions opérationnelles et de milieu. L'information sur la prise par unité d'effort de la pêcherie palangrière japonaise dans l'Atlantique est étendue dans le temps et dans l'espace; elle constitue donc une base de données importante pour les besoins de l'évaluation des stocks. Il n'est cependant pas certain que ces données illustrent les tendances qui peuvent être observées dans d'autres pêcheries palangrières qui exploitent les mêmes stocks. Le présent document analyse au moyen de techniques statistiques à variable multiple la prise spatio-temporelle par hameçon de grands pélagiques de l'Atlantique effectuée par les flottilles palangrières japonaise et taiwanaise. Les résultats indiquent que la CPUE est un indice qui est lié à certaines des espèces de thonidés capturées par les deux flottilles. Il se peut cependant que l'indice ne convienne pas pour caractériser l'abondance relative de l'espardon et des istiophoridés.

RESUMEN

La captura por unidad de esfuerzo de pesca se aplica ampliamente en los trabajos de evaluación de stock, bien directamente como índice de abundancia del stock en los modelos de producción o bien como índice para calibrar los análisis de cohorte. En las pesquerías de palangre, este índice representa, no sólo la abundancia relativa sino también la actuación relativa del arte bajo diversas condiciones operacionales y ambientales. La información sobre captura por esfuerzo de la pesquería palangrera japonesa en el Atlántico, es amplia en ámbito y tiempo; por tanto, representa una gran base de datos para la evaluación del stock. No está claro, sin embargo, si estos datos son representativos de las tendencias que

¹ Division of Marine Biology and Fisheries, Rosenstiel School of Marine and Atmospheric Science, University of Miami.

podrían observarse en otras flotas palangreras que pescan los mismos stocks. En el presente documento, se analiza la captura espacio-temporal por anzuelo de grandes pelágicos atlánticos por parte de la flotas palangreras de Japón y Taiwan, aplicando técnicas estadísticas múltiples y variadas. Los resultados muestran que la CPUE es un índice asociado con algunas de las especies de túnidos capturados por las dos flotas. No obstante, el índice podría no resultar apropiado para caracterizar la abundancia relativa de pez espada y marlín.

1. INTRODUCTION

Analyses based on catch and effort statistics have played an important role in assessing the status of exploitation of tunas and other large pelagic fish stocks in the Atlantic Ocean. A fundamental consideration for the application of stock assessment models to such fishery data is that catch per effort (CPUE) must be a valid index of relative abundance; hence, it must accurately reflect changes that occur in stock abundance. Because of long historic continuity and wide geographical coverage, catch and effort statistics of the Japanese longline fishery are extensively used to calculate indices of apparent relative stock abundance of several tuna and billfish species. For that purpose unadjusted CPUE estimates are usually standardized to take into consideration spatial-temporal differences in fishing intensity (Honma 1974) and differences in operational characteristics of the fleets (Kume 1985).

Characteristically, multinational longline fleets are able to concentrate, and sometimes to shift, fishing effort among selected target species. In these fisheries CPUE is traditionally expressed in number of fish caught per hook. The condition that one hook represents the basic unit of fishing effort brings forth the problem of gear saturation once a hook is occupied; hence, hook rates tend to measure the number of hooks that retained a fish rather than measuring local relative density of fish (Au 1986). Saturation due to differential abundance of target species such as albacore, yellowfin, or bigeye tuna may therefore modify the efficiency with which the gear catches non-target species such as swordfish and other billfish. On the other hand, gear interaction under fixed population densities may significantly affect catchability of a single hook and therefore gear competition will be reflected in either a decrease or an increase in CPUE of one fleet relative to the presence or absence of other fleets operating in the same area. Under these considerations it may not be entirely appropriate to estimate CPUE on a single species and single fleet basis.

In this report an attempt is made to discriminate among temporal-spatial associations of relative abundance indices of large pelagic species captured by the Japanese and Taiwanese Atlantic longline fleets. Correlations among these canonical variables will be used to elaborate on the adequacy of data integration procedures generally required for stock assessment work.

2. MATERIALS AND METHODS

The data used in this report are catch in number of fish and effort in number of hooks of the Japanese and Taiwanese longline fisheries in the Atlantic Ocean taking the years 1982 and 1983 as examples. Data were obtained from National Marine Fisheries Service, Miami Laboratory tapes containing data retrieved from ICCAT files. Data were stratified by months and by 5° Latitude x 5° Longitude squares. All those squares containing concurrent records of fishing effort activities from both fleets were retrieved into separate files and used in the comparative analyses.

An average monthly CPUE by species and fleet for the entire Atlantic was estimated as the ratio between total monthly catch in concurrent squares and the total corresponding effort. Species considered in the analyses are albacore, bigeye tuna, yellowfin tuna, swordfish, and pooled billfish species. Billfish species were pooled to avoid many zero catches. The species pooled were blue marlin, white marlin, sailfish, spearfish and unclassified billfishes.

Under the null hypothesis, average monthly tuna and billfish CPUE series generated by Taiwanese and Japanese fleets should follow similar trends once multivariate effects are considered. The first step in the analyses was to develop a visual correspondence among CPUE by species, months and fleets. For

this purpose star plots were constructed from the data base considering that rays in the star plots are re-scaled to range from c to 1, where c is the desired length of the smallest ray relative to the largest (c may be zero). If x_{ij} is the j^{th} measurement of the i^{th} variable then the scaled variable is

$$x_{ij}^* = (1-c)(x_{ij} - \min_i(x_{ij})) / (\max_i(x_{ij}) - \min_i(x_{ij})) + c$$

To portray p variables, p rays are chosen whose directions are equally spaced around the circle.

For the i^{th} re-scaled observation, a star whose j^{th} ray is proportional to x_{ij}^* is needed. If the plotting origin is set at the center of the star and the maximum radius is R , then the required star is obtained by computing and connecting the $p+1$ points,

$$P_{ij} = (x_{ij}^* R \cos(\delta_j), x_{ij}^* R \sin(\delta_j))$$

for j ranging from 1 to p , and where δ is the angle of the j^{th} ray from the horizontal.

A formal statistical analysis of the data was accomplished from canonical correlations and canonical coefficients estimated from the multivariate data base. Canonical variate analysis deals with interrelationships among two sets, or vectors, of variate (species' CPUE) values such that a few linear combinations of the variates that account for nearly all the variance of the data can be estimated. Hence, canonical analysis examines the relationships among linear combinations of the original variates rather than among the raw data (Pilou 1969).

The input to the analysis consisted of p Taiwanese variates on each month resulting in a vector of CPUE's (x_1, x_2, \dots, x_p) and of q Japanese variates yielding the CPUE vector ($y_{p+1}, y_{p+2}, \dots, y_{p+q}$). In this case $p = q$; therefore, the objective was to find p and q linear combinations of the x 's and y 's of the type

$$E_i = a_{i1}x_1 + a_{i2}x_2 + \dots + a_{ip}x_p, \quad (i = 1, \dots, p),$$

$$\text{and } N_j = b_{j1}y_{1+p} + b_{j2}y_{2+p} + \dots + b_{jq}y_{q+p}, \quad (j = 1, \dots, q)$$

that maximize between-set correlations between p pairs of variates. Therefore, the canonical variates E_i and N_j have the following properties:

1. All the E_i 's are uncorrelated with one another.
2. All the N_j 's are uncorrelated with one another.
3. The pair of canonical variates E_i and N_j have canonical correlations R_i ($i = 1, \dots, p$) but all other correlations between E_i 's and N_j 's are zero.

Plots of canonical variates and their respective canonical correlations were subsequently used to analyze correspondence of CPUE indices between the two fleets.

3. RESULTS AND DISCUSSION

Spatio-temporal distribution of $5^\circ \times 5^\circ$ Latitude-Longitude squares where Japanese and Taiwanese effort was deployed during the two case years (1982 and 1983) are shown by month in figures 1 and 2, respectively. In the figures, black dots indicate squares where fishing effort was concurrent by the two fleets. The figures indicate that fishing activities by the Japanese and Taiwanese fleets did not overlap considerably throughout the Atlantic and that the degree of overlapping was greater in 1982 than in 1983. This latter effect is attributed to a wider distribution of the Taiwanese fishing effort during 1982. However, concurrent monthly effort occurred approximately in the same general areas during the two years considered in the analyses. July, November and December were the months with the least effort overlap in 1982, whereas May, June, July and November were the months with the least effort overlap in 1983.

A 1982 star plot representation of multivariate (CPUE) information by month and fleets is shown in figure 3. Similar plot for the Taiwanese fleet for 1983 is shown in figure 4. Identification of rays in the star plots are obtained from figure 5 where albacore is located at 3 o'clock, followed counter clockwise by bigeye tuna, yellowfin tuna, skipjack tuna, swordfish and billfishes. Star plots are directly comparable for shape and size. These two attributes allows one to discriminate for monthly differences in fishing efficiency between the fleets as indicated by the general size of the plots, and to discriminate species contributions to total CPUE according to the shape of the plots. Thus, in 1982 (Figure 3) the Taiwanese fleet apparently performed better than the Japanese fleet during the months of February, June, August, and October, whereas performance during March, April and July was roughly the same for both fleets. Star plot shapes were very similar during the months of January, February, March, May, July, September, and October, indicating that the relative CPUE composition by species during those months was approximately similar. However, significant departures in general shape are observed in June, August, November, and December of 1982. Similar analyses for 1983 indicate some major changes in the relative shape and size of the star plots. During that year the Taiwanese fleet showed superior performance in January, February, March, April and December, whereas similarity of shapes are only observed in January and May.

Average CPUE by species and months corresponding to all effort overlapping squares are presented in Tables 1 and 2 for the Taiwanese and Japanese fleets, respectively. The information contained in those tables was used to generate canonical variate coefficients and canonical correlations. Resulting values are presented in Tables 3 and 4 for 1982 and 1983 data, respectively. Canonical correlations were not significant for any pair of canonical variates with the only probable exception of albacore in 1982 ($R=0.975$; $P>0.1071$). A comparative analysis of canonical correlations between 1982 and 1983 corroborates preliminary results obtained from star plots which indicate that there is less association between canonical variates in 1983 than in 1982. The lowest canonical correlations, hence indicating the largest degree of disassociation, were obtained among non-target species such as swordfish and billfishes.

Graphical representations of pairs of monthly canonical variates (E_i, N_i) by species and year are shown in Figures 6 and 7. Linear trends with varying dispersion according to their canonical correlations are observed for albacore ($R_{1982} = 0.975$; $R_{1983} = 0.887$) and bigeye tuna ($R_{1982} = 0.922$; $R_{1983} = 0.791$). These trends, although not significantly correlated, still indicate a general linear correspondence between variates of operationally different longlines. This condition may be interpreted as albacore and bigeye tuna being distributed over less stratified depth ranges than the other species considered. On the other hand, deviations of the slope of these trends from 1 may be interpreted as differences in fishing efficiency between fleets.

Swordfish and billfish plots show almost no association among monthly canonical variates; therefore, there is no reason to believe that the fleets are operating on similar stock densities. Because the pattern of dispersion observed in the figures also varies significantly between years, it is likely that significant between-year differences in vertical population density stratifications may have occurred within concurrent effort squares. Such differences could only be explained if oceanographic data (such as depth of thermocline) and qualitative data on landings (such as size or age differences in the fish landed by the fleets) were incorporated into the analyses.

4. CONCLUSIONS

Canonical variate analysis demonstrated that relative abundance indices of tuna and billfish derived from Taiwanese and Japanese Atlantic longline fisheries do not correlate in a simple manner. Only CPUE derived for some target species, such as albacore and bigeye tuna, appeared to follow independent general canonical variate trends, implying an approximate linear association between the indices developed from the two fleets. A plausible explanation for such an association may be that behavioral characteristics of these species make them approximately equally available to fleets operating in concurrent effort areas but differing in fishing tactics.

Low canonical correlations estimated for swordfish and billfish are the result of a lack of general trends in canonical variates observed with those species. Disassociation between relative indices of

abundance might be an indication that, at least in the areas considered, varying availability of these fish to the gears, both within and between years, may be the result of biological and oceanographic considerations not included in the analyses. The implication is, therefore, that such interactions render integration of billfish statistical data bases impossible.

The powerful statistical techniques used in these analyses have not been previously used to resolve fishery problems, such as to elucidate questions of gear saturation, gear interactions, and effort standardization. The results obtained in this report demonstrate the usefulness of the techniques when applied to complex data systems and suggest potential avenues for new research.

5. REFERENCES

AU, D., 1986. Interpretation of longline hook rates. Coll. Vol. Sci. Pap. ICCAT. Vol. XXV (SCRS/85/68), pp. 377-385.

HONMA, M., 1974. Estimation of overall effective fishing intensity of tuna longline fishery-yellowfin tuna in the Atlantic Ocean as an example of seasonally fluctuating stocks. Bull. Far. Seas Fish. Res. Lab., (10), pp. 63-85.

KUME, S., 1985. An analysis on the stock abundance of Atlantic bigeye tuna caught by Japanese longline fishery. Coll. Vol. Sci. Pap., ICCAT. Vol. XXIII(2), pp. 248-253.

PIELOU, E.C. 1969. An Introduction to Mathematical Ecology. Wiley-Interscience, New York. 286 p.

6. ACKNOWLEDGMENT

The author expresses his appreciation to Dennis Lee, National Marine Fisheries Service, Southeast Fisheries Center, Miami Laboratory, for his cooperation in translating tapes to the Miami Lab format and for providing invaluable assistance with the Miami Lab Taiwanese data files.

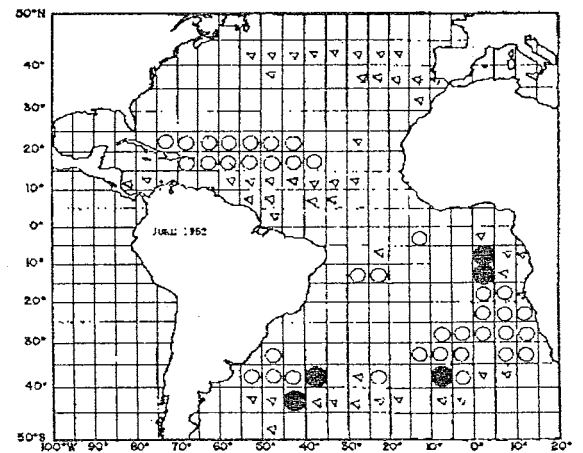
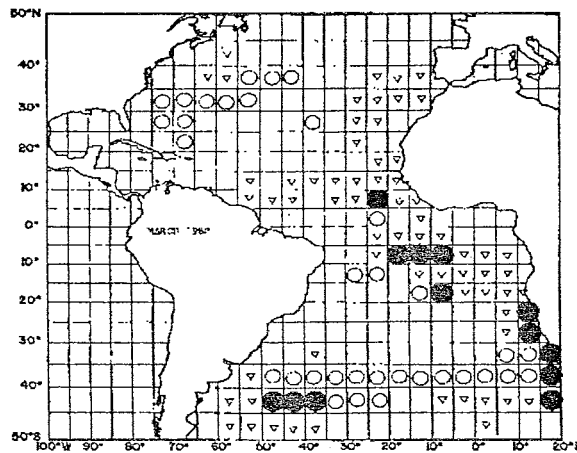
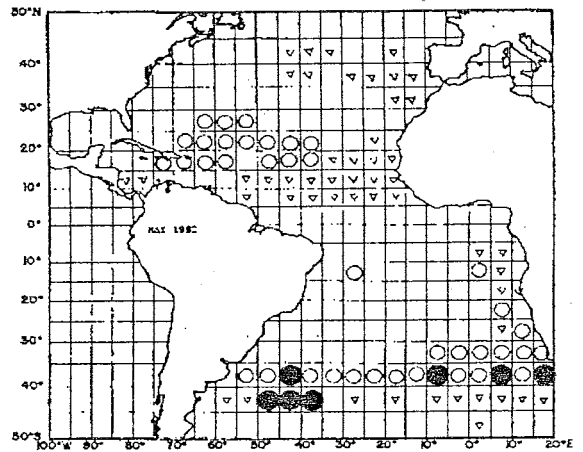
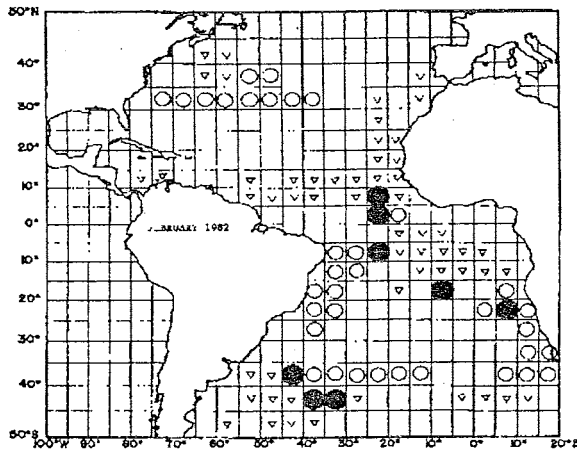
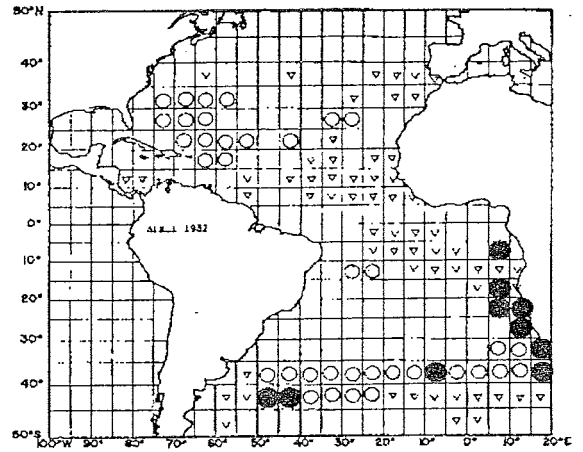
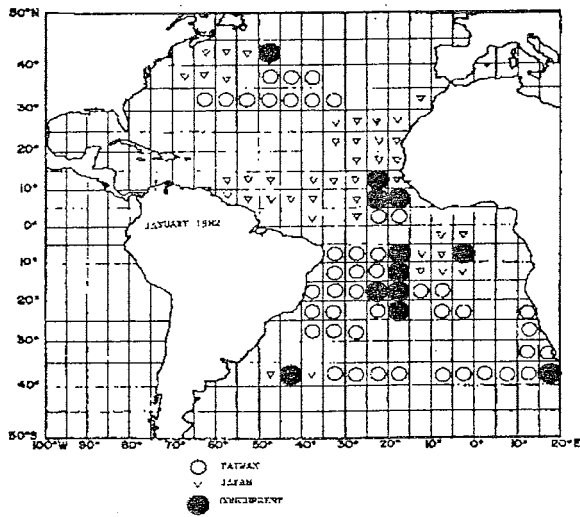


Fig. 1 Monthly spatial distribution of fishing effort deployed by Taiwanese and Japanese longline fleets in 1982.

Fig. 1 Continued.

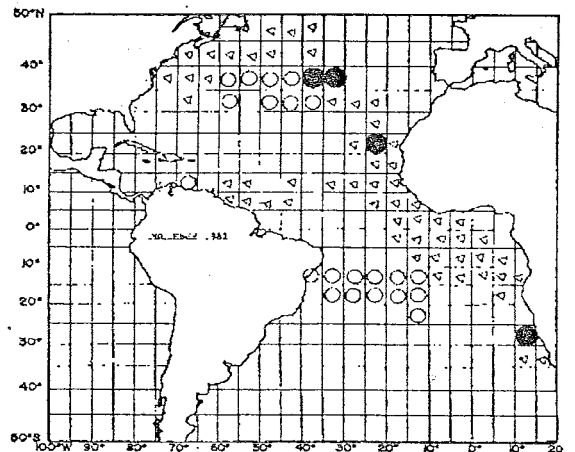
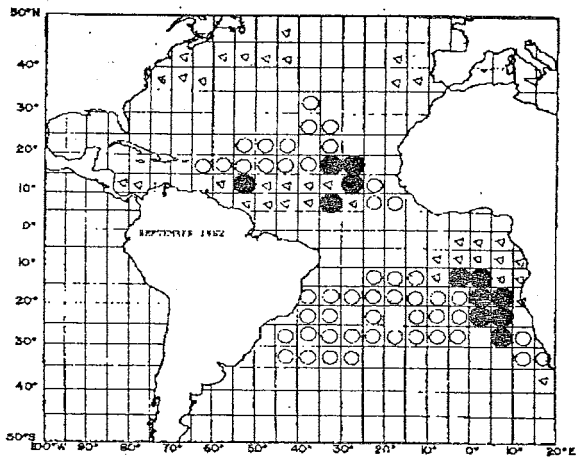
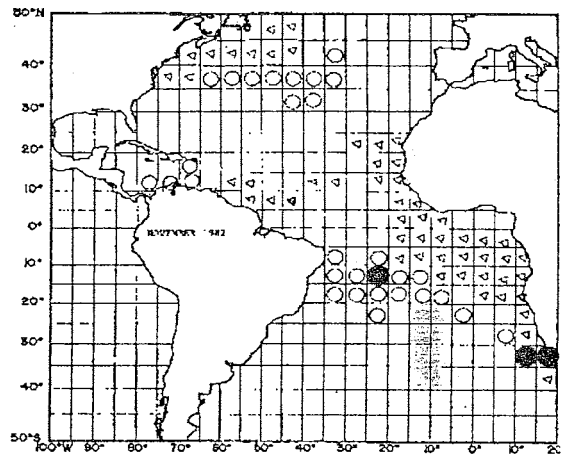
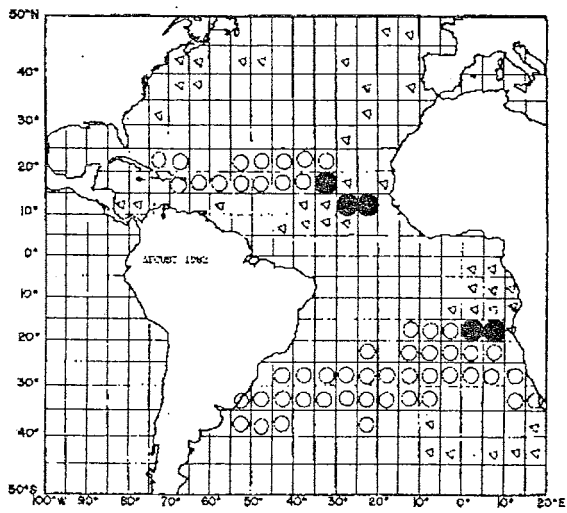
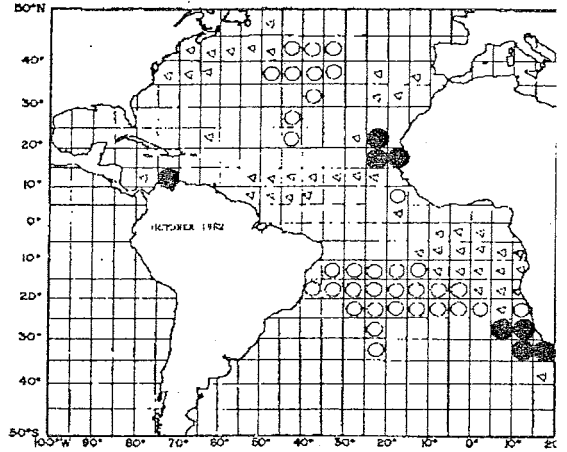
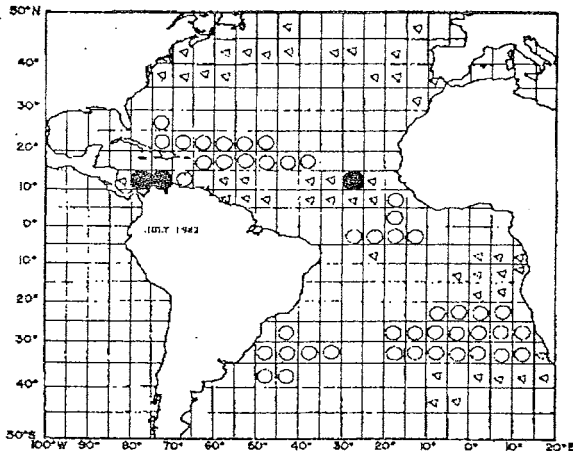


Fig. 1 Continued.

Fig. 1 Continued.

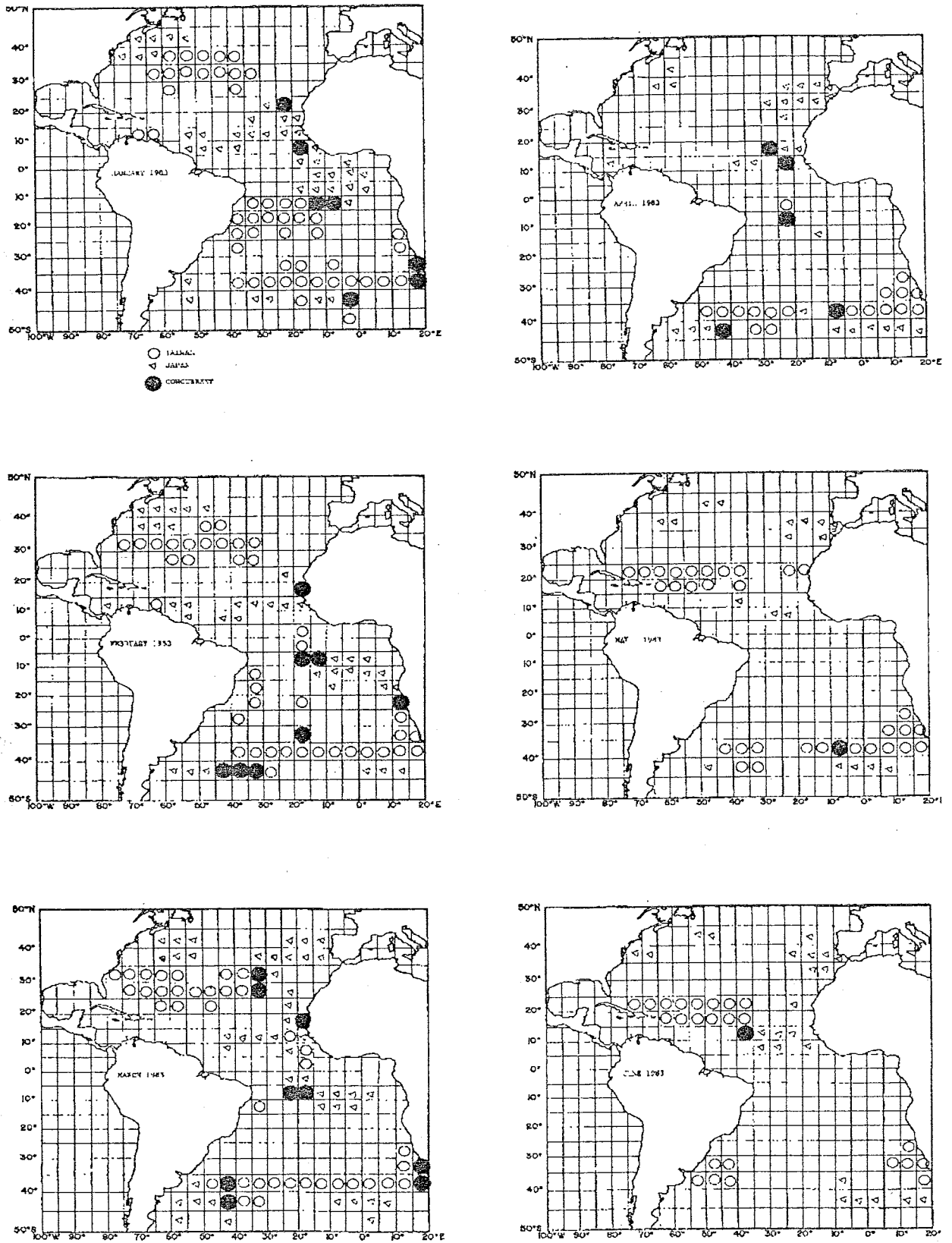


Figure 2 Monthly spatial distribution of fishing effort deployed by Taiwanese and Japanese longline fleets in 1983.

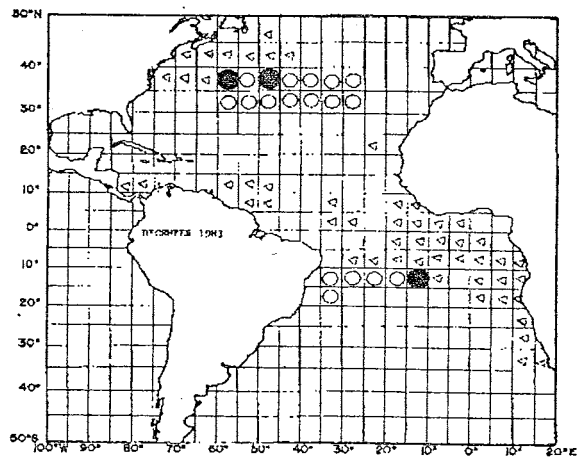
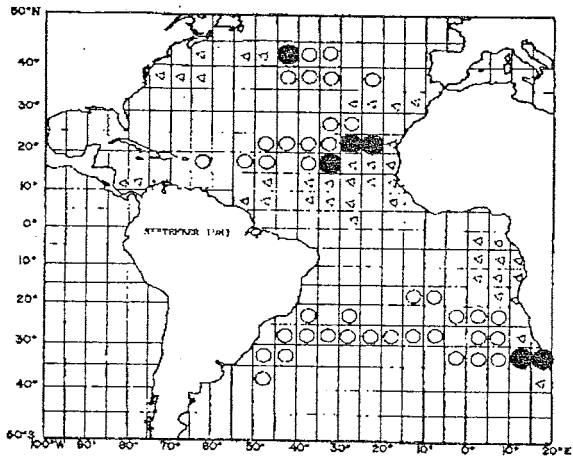
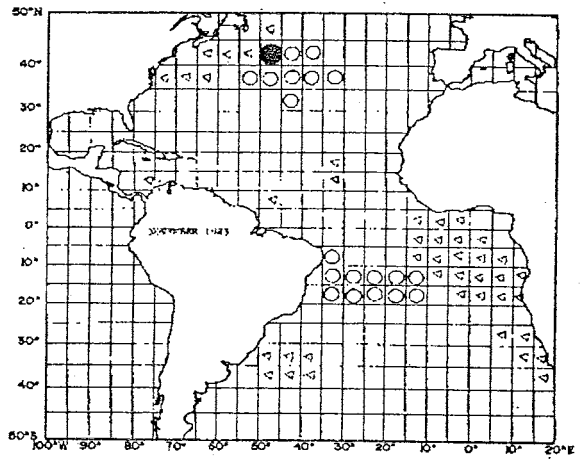
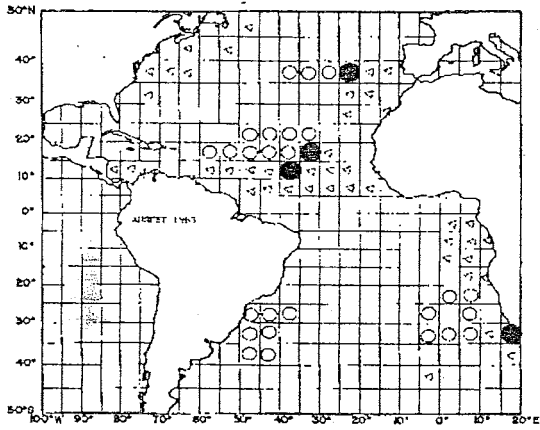
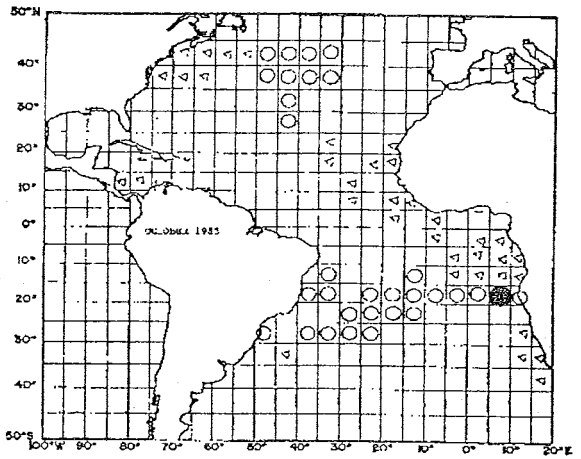
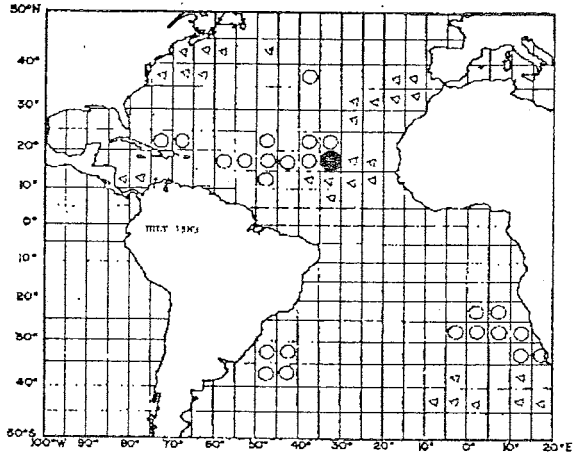
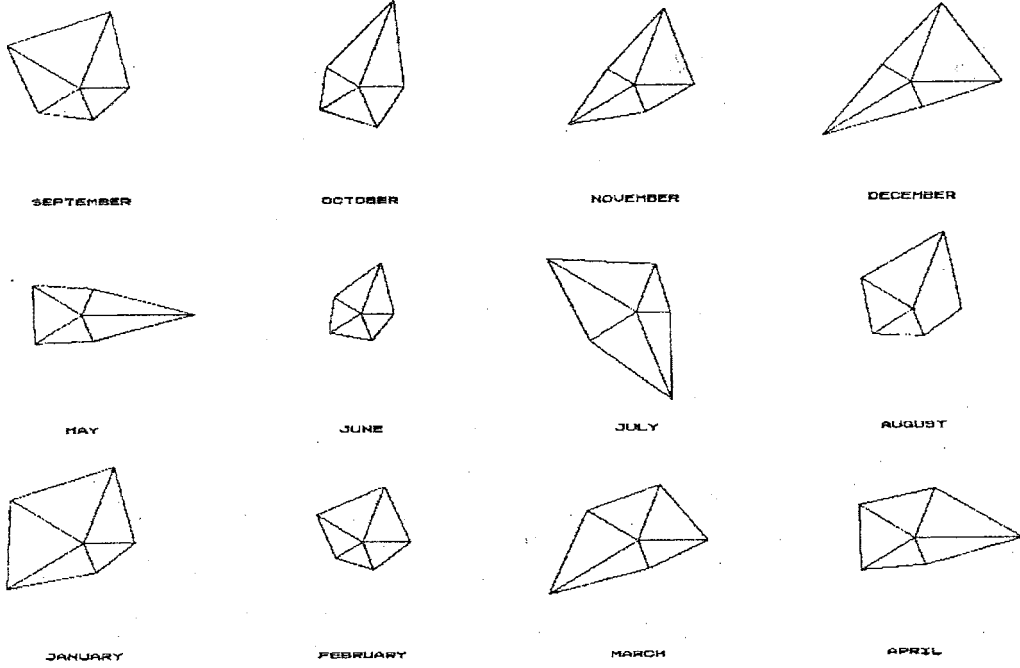


Figure 2 Continued.

JAPAN



TAIWAN

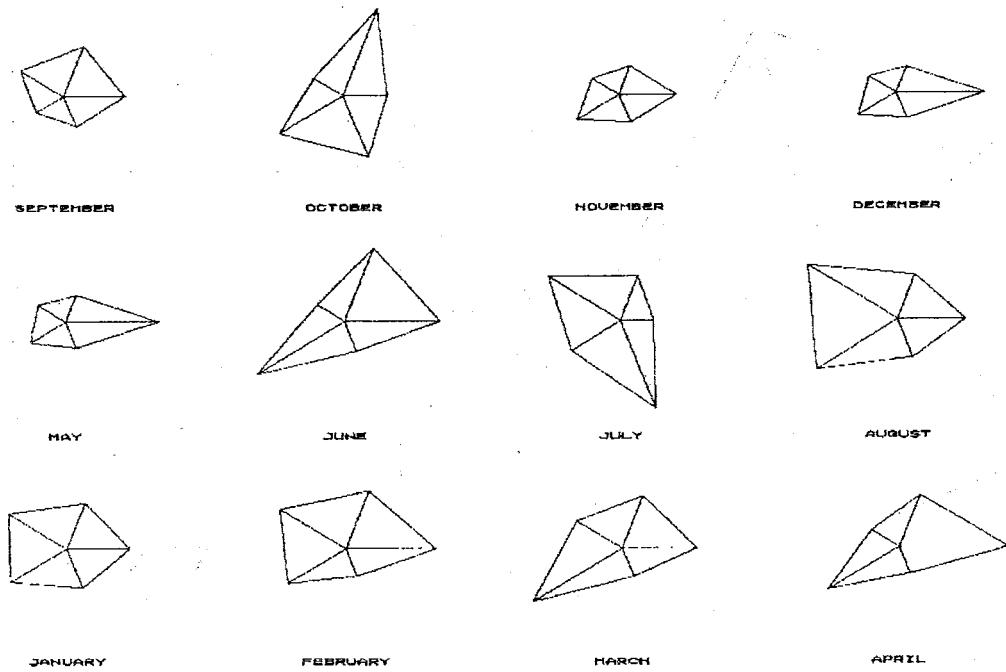


Figure 3. Star plots of standardized CPUE according to species, months and fleets in 1982.

TAIWAN

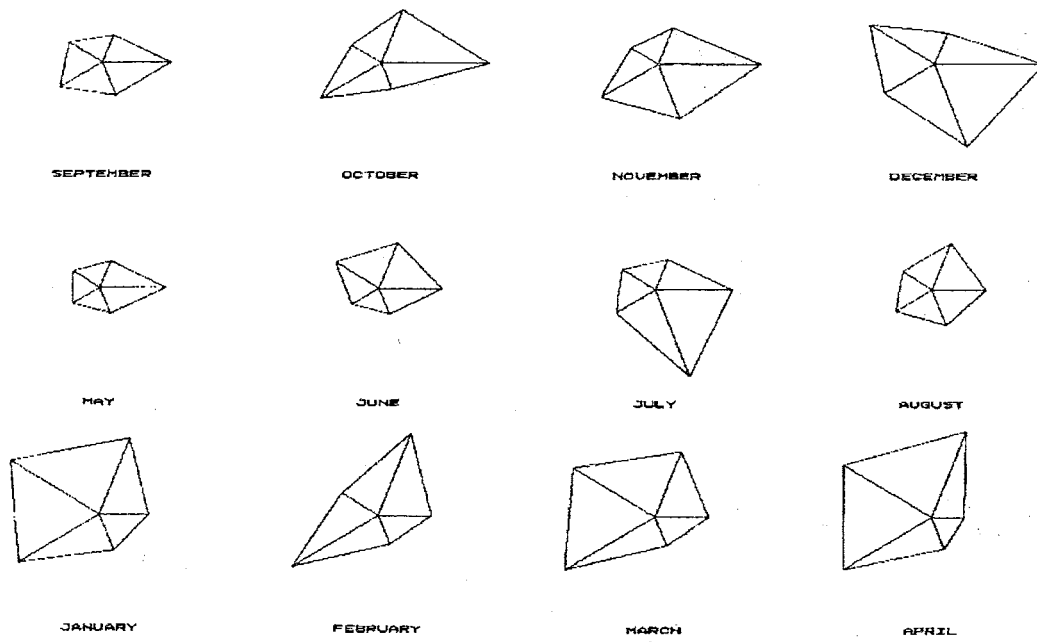


Figure 4. Star plots of standardized CPUE according to species and months for the Taiwanese fleet in 1983.

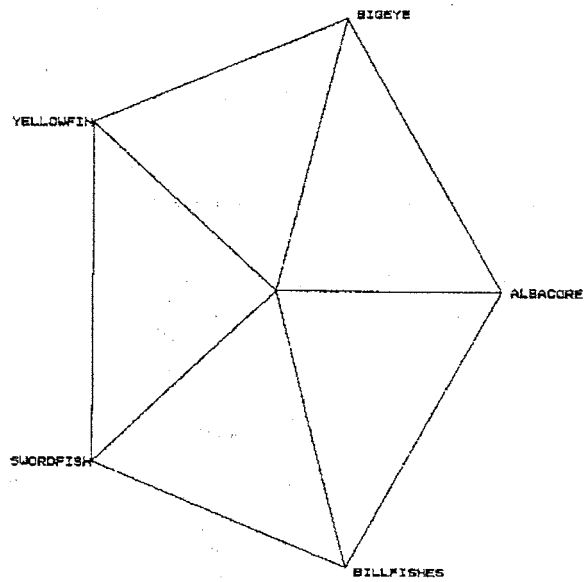


Figure 5. Star plot species identification chart.

ALB 1982

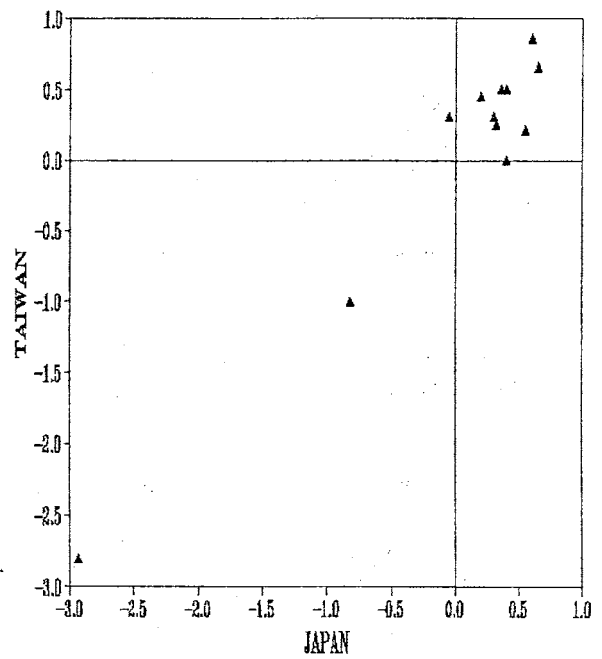


Figure 6. Series of canonical variate graphs by species, 1982.

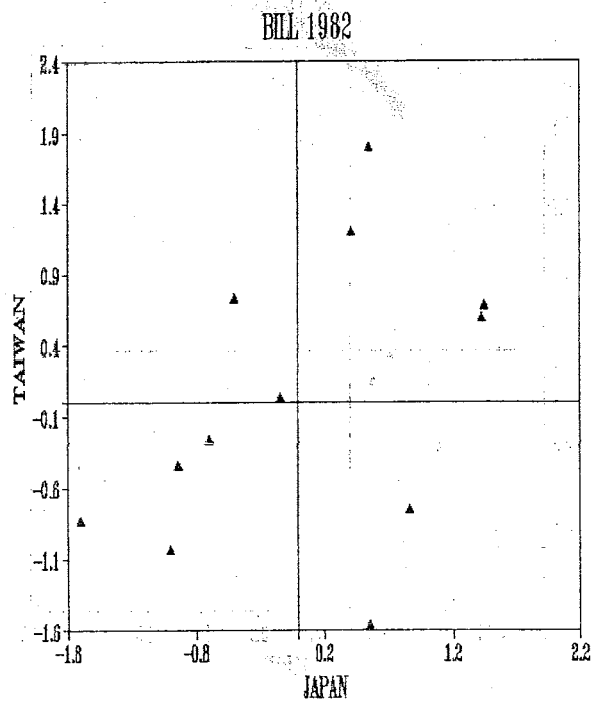
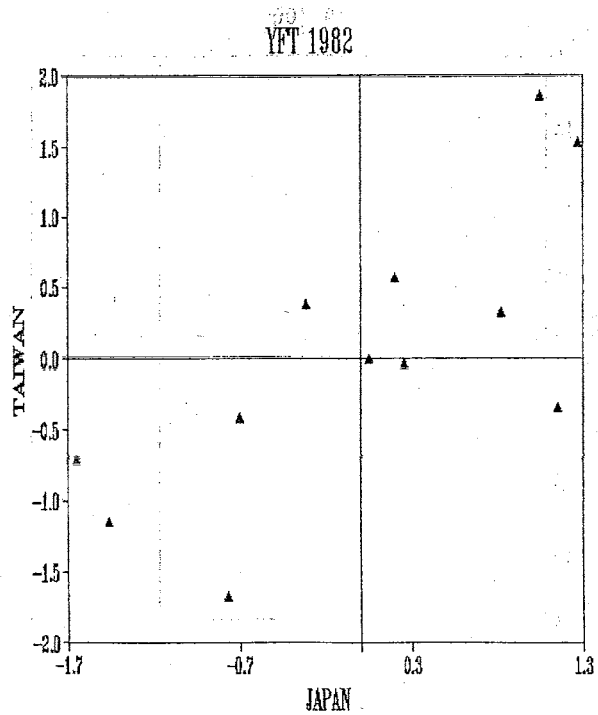
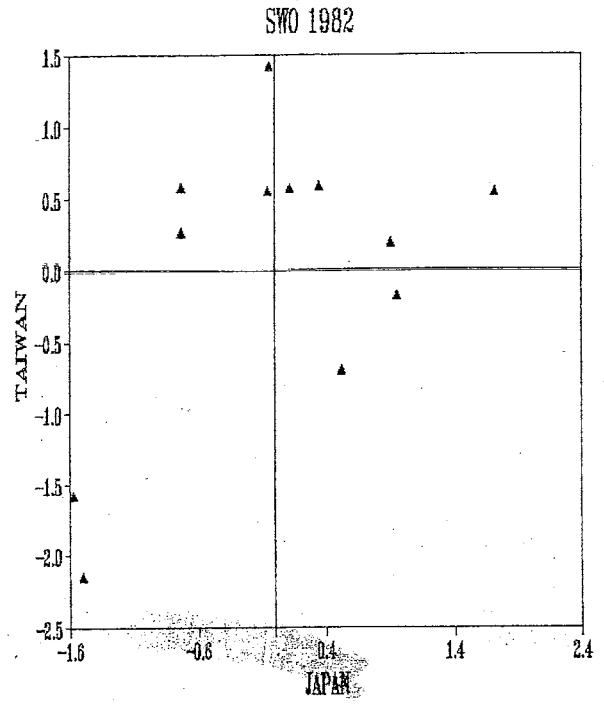
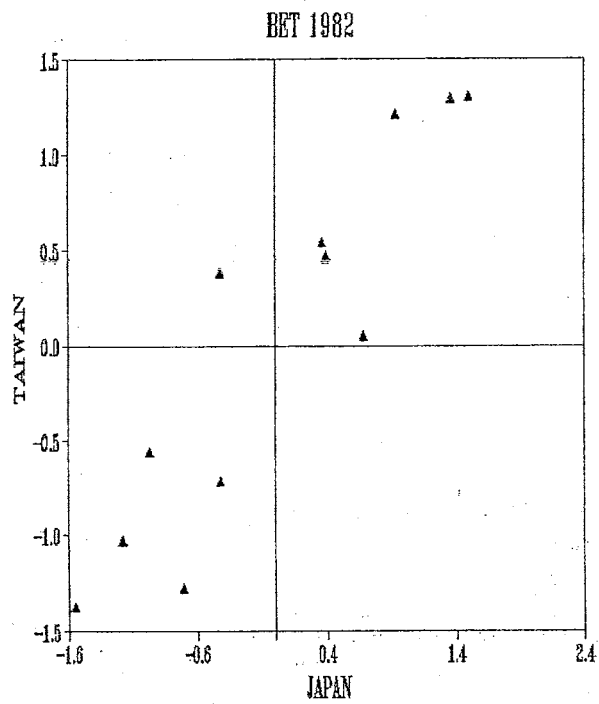


Figure 6. Continued...

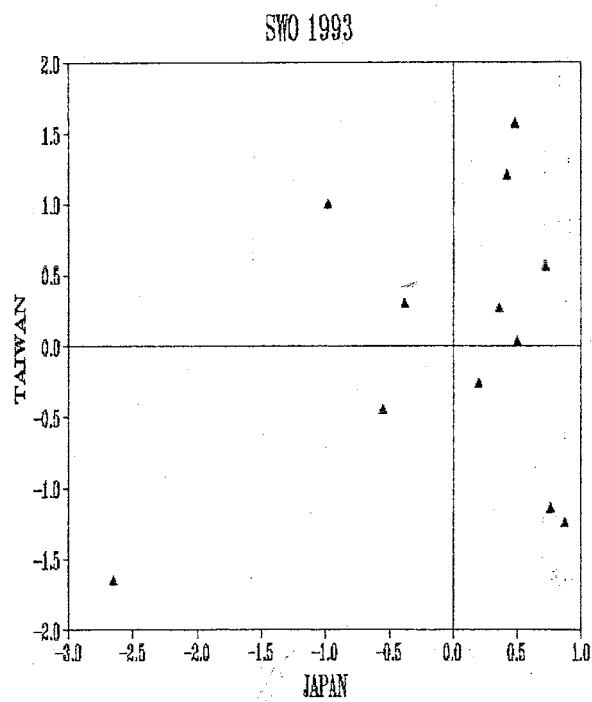
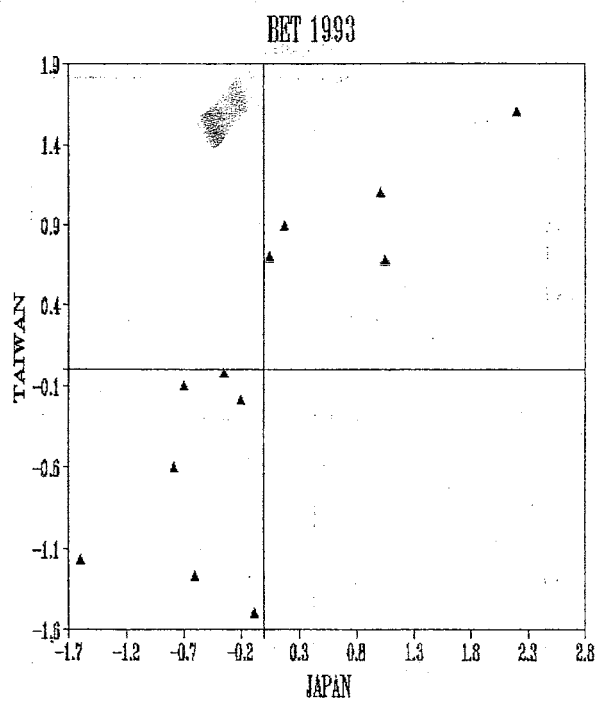
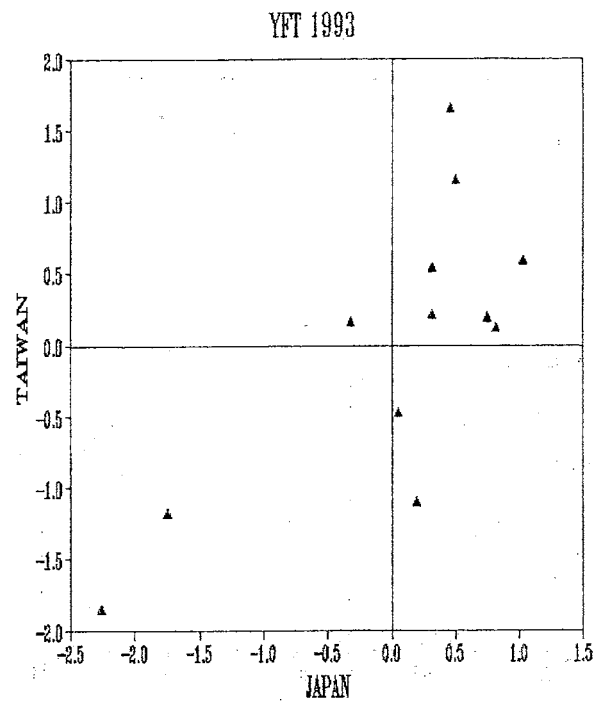
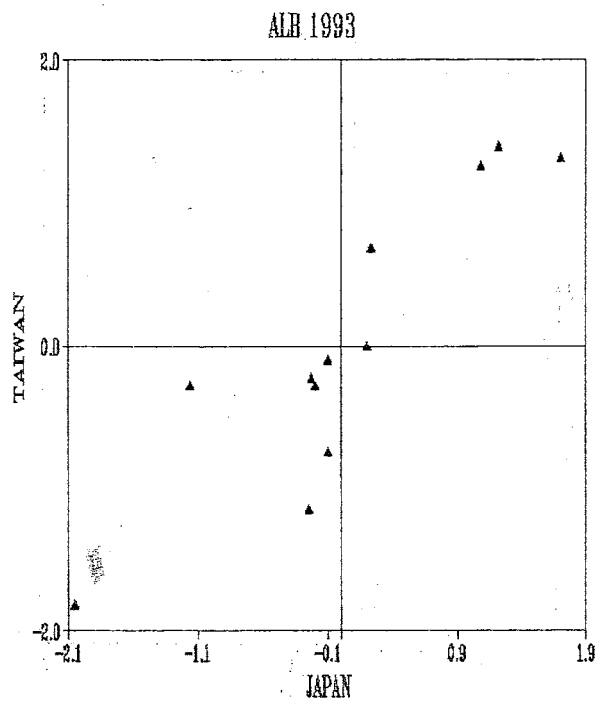


Figure 7. Series of canonical variate graphs by species. 1983.

Table 1. Average monthly number of fish caught per hook realized by the Taiwanese fleet in 5⁰ X 5⁰ squares of the Atlantic where Japanese fishing effort was also deployed in the years 1982 and 1983. Effort is in number of hooks.

MONTH	YR	EFFORT	ALBACORE	BIGEYE	YELLOW	SWORD	BILLTGT
JANUARY	82	520000.	.0117732	.0023892	.0148028	.0002490	.0002625
FEBRUARY	82	349000.	.0223894	.0035998	.0183111	.0002612	.0000310
MARCH	82	1573200.	.0164838	.0030704	.0039056	.0004637	.0000518
APRIL	82	1459200.	.0302181	.0029698	.0006910	.0003425	.0000065
MAY	82	2168900.	.0229626	.0003676	.0001908	.0001071	.0000015
JUNE	82	276400.	.0244603	.0050801	.0001675	.0004556	.0000548
JULY	82	66100.	.0009083	.0021856	.0215222	.0002008	.0012224
AUGUST	82	137100.	.0141292	.0021374	.0294711	.0004114	.0002272
SEPTEMBER	82	385400.	.0112026	.0027984	.0077344	.0000543	.0000902
OCTOBER	82	264500.	.0048847	.0064833	.0009615	.0002976	.0007356
NOVEMBER	82	550800.	.0097980	.0005706	.0000667	.0001525	.0000510
DECEMBER	82	847200.	.0219263	.0003778	.0000490	.0001264	.0000007
JANUARY	83	148300.	.0127509	.0040603	.0019025	.0002951	.0001099
FEBRUARY	83	690500.	.0149150	.0045034	.0003023	.0003199	.0000234
MARCH	83	1291900.	.0151549	.0031826	.0016708	.0003369	.0000315
APRIL	83	47200.	.0064577	.0048223	.0018451	.0003278	.0000623
MAY	83	3300.	.0196970	.0000000	.0000000	.0000000	.0000000
JUNE	83	2000.	.0190000	.0015000	.0005000	.0000000	.0000000
JULY	83	134000.	.0248284	.0002985	.0001940	.0000672	.0006587
AUGUST	83	380200.	.0153638	.0015702	.0001026	.0000513	.0001041
SEPTEMBER	83	175600.	.0209105	.0000861	.0001962	.0000876	.0000367
OCTOBER	83	43800.	.0379271	.0021795	.0000957	.0001794	.0000120
NOVEMBER	83	6200.	.0358065	.0008065	.0000000	.0001613	.0000326
DECEMBER	83	200300.	.0390906	.0003565	.0011666	.0001242	.0006201

Table 2. Average monthly number of fish caught per hook realized by the Japanese fleet in 5⁰ X 5⁰ squares of the Atlantic where Taiwanese fishing effort was also deployed in the years 1982 and 1983. Effort is in number of hooks.

MONTH	YR	EFFORT	ALBACORE	BIGEYE	YELLOW	SWORD	BILLTGT
JANUARY	82	1536704.	.0018827	.0083219	.0234444	.0008852	.0002800
FEBRUARY	82	242870.	.0015856	.0052118	.0094292	.0003217	.0001439
MARCH	82	3865471.	.0038912	.0052583	.0121361	.0010156	.0001477
APRIL	82	878742.	.0078990	.0043187	.0145310	.0006195	.0000853
MAY	82	622957.	.0080625	.0008186	.0113928	.0005505	.0000000
JUNE	82	254970.	.0001116	.0045319	.0000349	.0003808	.0000210
JULY	82	343256.	.0002131	.0040556	.0317267	.0005413	.0043607
AUGUST	82	787390.	.0016737	.0085580	.0125914	.0004774	.0000477
SEPTEMBER	82	1118650.	.0016520	.0083624	.0233370	.0004870	.0004482
OCTOBER	82	576092.	.0013470	.0098737	.0031909	.0004563	.0011655
NOVEMBER	82	99447.	.0028041	.0083265	.0001449	.0007674	.0001449
DECEMBER	82	257490.	.0060934	.0086925	.0009356	.0010160	.0000404
JANUARY	83	1534885.	.0007528	.0067994	.0087434	.0007546	.0001200
FEBRUARY	83	1075767.	.0013314	.0074804	.0042345	.0009006	.0001107
MARCH	83	1222273.	.0068447	.0105178	.0044831	.0009878	.0001317
APRIL	83	174997.	.0025929	.0074528	.0004584	.0004547	.0001002
MAY	83	165696.	.0016295	.0000000	.0000000	.0000121	.0000000
JUNE	83	31692.	.0034394	.0153035	.0044806	.0007680	.0006211
JULY	83	28287.	.0003535	.0136105	.0009192	.0006717	.0002121
AUGUST	83	146342.	.0007596	.0063750	.0056374	.0006703	.0001680
SEPTEMBER	83	316281.	.0012610	.0065365	.0017628	.0012815	.0000581
OCTOBER	83	212550.	.0006986	.0100988	.0000462	.0005694	.0000000
NOVEMBER	83	27167.	.0030184	.0008834	.0000000	.0015828	.0000000
DECEMBER	83	25319.	.0093750	.0052400	.0032960	.0004054	.0014362

Table 3. Canonical correlations and canonical variate coefficients according to species and fleets. 1982

1982 Canonical Correlations						
Number	Eigenvalue	Canonical Correlation	Wilks Lambda	Chi-Square	D.F.	Sign. Level
1	.9507	.9750	.0021	34.039	25	.1071
2	.8508	.9224	.0416	17.485	16	.3549
3	.5458	.7388	.2790	7.022	9	.6348
4	.2657	.5154	.6141	2.682	4	.6124
5	.1637	.4046	.8363	.983	1	.3214
Coefficients for Canonical Variables: Taiwan						
Albacore	-0.22973	0.61628	-1.50793	-0.10838	-0.49774	
Bigeye	0.08623	-0.96037	-0.60858	-0.71489	0.29700	
Yellowfin	-0.01941	-0.82608	-0.60089	0.60714	-0.30417	
Swordfish	0.20082	0.46961	1.01659	-0.08444	-0.86447	
Billfishes	-1.15801	0.94250	-0.60645	-0.23265	-0.49010	
Coefficients for Canonical Variables: Japan						
Albacore	-0.22694	0.60129	-0.73935	0.08155	1.10772	
Bigeye	-0.23805	-0.40311	-0.01582	0.00451	1.22257	
Yellowfin	0.01262	-0.57315	-0.43407	1.03422	-0.00745	
Swordfish	0.15981	0.38259	0.96162	0.46203	-0.43649	
Billfishes	-1.08417	0.61761	0.16036	-0.45952	0.35378	

Table 4. Canonical correlations and canonical variate coefficients according to species and fleets. 1983

1983 Canonical Correlations						
Number	Eigenvalue	Canonical Correlation	Wilks Lambda	Chi-Square	D.F.	Sign. Level
1	.7859	.8865	.0335	18.675	25	.8125
2	.6263	.7914	.1566	10.197	16	.8561
3	.5417	.7360	.4190	4.784	9	.8527
4	.0800	.2828	.9143	.493	4	.9742
5	.0062	.0789	.9938	.034	1	.8530
Coefficients for Canonical Variables: Taiwan						
Albacore	0.46123	0.27533	-0.52648	-0.22871	-1.30187	
Bigeye	1.76357	-1.07639	0.57073	0.87009	-1.43313	
Yellowfin	0.26874	-0.48708	-1.31885	-0.52687	-0.03481	
Swordfish	-1.98745	1.14283	-0.02220	0.39870	0.65907	
Billfishes	0.69838	0.17034	0.19964	0.97955	0.51987	
Coefficients for Canonical Variables: Japan						
Albacore	-1.01754	-0.20846	-1.08870	-0.25470	-0.54996	
Bigeye	0.11146	-0.27630	-0.01917	0.44391	-0.91169	
Yellowfin	-0.19104	-0.74521	-0.23161	0.33904	0.59639	
Swordfish	-0.10378	0.70643	0.14832	0.80231	0.18587	
Billfishes	1.42623	0.70655	0.19282	0.36494	0.56575	