APPENDIX D

REPORT OF THE WORKSHOP ON EVALUATING KRILL FLUX FACTORS

(Cape Town, South Africa, 21 to 23 July 1994)

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EVALUATING KRILL FLUX FACTORS
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The Workshop on Evaluating Krill Flux Factors was held from 21 to 23 July 1994 in the Sea Fisheries Research Institute, Cape Town, South Africa. Dr Vere Shannon, Director of the Institute, welcomed participants.

2. A Preliminary Agenda, circulated prior to the meeting, was adopted. Dr W. de la Mare (Australia) was elected Chairman for the meeting. Terms of reference for the workshop were given in SC-CAMLR-XII, paragraph 2.29. Further specification of the data and analyses required were given in SC-CAMLR-XII, Annex 4, Appendix D.

3. The Agenda, lists of participants and papers submitted to the workshop are given as Attachments A, B and C. The report was prepared by Drs D. Agnew (Secretariat), M. Basson (UK), W. de la Mare (Australia), R. Hewitt and E. Hoffman (USA) and E. Murphy and Mr M. Stein (Invited Experts).

DATA AVAILABILITY AND PREPARATION

4. The data required for the workshop to proceed were outlined in SC-CAMLR-XII, paragraph 2.30. This section describes the available data and their preparation for the meeting.

5. Krill acoustic survey data were available from the BIOMASS experiments which covered the following areas:

FIBEX: *Odissey* - small area north of South Georgia, and another to the east of Subarea 48.2.
Dr Eduardo L. Holmberg - western Subarea 48.2, including areas to the west and north of the South Orkneys.
Walther Herwig - large area overlapping Subareas 48.1, 48.2 and Division 41.3.2 north of the Convention Area.
Itzu Mi - Drake Passage and Bransfield Strait.

FIBEX cruises took place from January to March 1981.

SIBEX 1: *Polarstern* - area surrounding Elephant Island; October to November 1983.
Professor Siedlecki - Drake Passage and Bransfield Strait south to Anvers Island; December to January 1983/84.

SIBEX 2: *John Biscoe* - Drake Passage and Bransfield Strait south to Anvers Island; January to February 1985.
Capitan Alcazar - Bransfield Strait; January to February 1985.
Walther Herwig - Peninsula south to 68°S; March to April 1985.
Polarstern - around Elephant Island; November to December 1984.

6. These data were prepared prior to the meeting by the Data Manager using the same techniques as have been used in previous analyses (WS-Flux-94/4) (see also Trathan *et al*. (1992))[1]. The data available to the workshop were therefore latitude, longitude, krill density, integration interval distance, top and bottom integration depths and a day/night flag for each integration interval stored in the database. Most data sets had integration depths of 150 to 200 m.

7. Data on current velocity were available from two sources:

- a single time slice (FR2191) of the FRAM (Fine Resolution Antarctic Model) was provided at a resolution of 0.5° longitude x 0.25° latitude for Subareas 48.1, 48.2 and 48.3 south to 64.5°S by Dr Murphy. Data available were latitude, longitude, speed (cm/sec) in northerly and easterly directions. Prior to use by the workshop, they were converted to the standard latitude, longitude, direction and speed, averaged over the top 250 m; and

- geostrophic current velocities derived from CTD samples were provided by Mr Stein and Dr M. Naganobu (Japan). These data covered three years of sampling by Germany off the Antarctic Peninsula (1986, 1987 and 1990), a number of samples from Subarea 48.2 and two years sampling by Japan and Germany in the vicinity of the Subarea 48.1/48.2 boundary (1988 and 1992). All data were provided in the standard format of latitude, longitude, direction and speed, and averaged over the upper 200 m. Maximum reference depth for the calculations was 800 m. Interpolated flow vectors for the German data were presented in WS-Flux-94/6.

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[1] Trathan, P.N., D.J. Agnew, D.G.M. Miller, J.L. Watkins, I. Everson, M.R. Thorley, E. Murphy, A.W.A. Murray and C. Goss. 1992. Krill biomass in Area 48 and Area 58: recalculations of FIBEX data. In: *Selected Scientific Papers (SC-CAMLR-SSP/9). CCAMLR*, Hobart, Australia: 157-181.

8. Figure 1 shows the extent of all these data sets together with krill catch distribution by fine-scale area.

ANCILLARY DATA

9. A number of additional data sources were available to the group, including passive tracer streamlines derived using the FRAM (WS-Flux-94/9), ship displacement trajectories (WS-Flux-94/10), buoy paths (WS-Flux-94/8) and iceberg drift paths (WS-Flux-94/6).

10. Latitude, longitude and date of buoy positions were extracted from Figure 8 of WS-Flux-94/8, and average speeds between consecutive positions were calculated. A comparison of these data with hydrodynamic data is presented in Table 1.

11. Iceberg drift speeds in WS-Flux-94/6 did not contain any information on direction. Average speed across boundaries of subareas (see paragraph 13) was nonetheless calculated for comparison with other data. On the basis of Figure 1 in WS-Flux-94/6, a general direction of 30° was assumed. Results are given in Table 3.

ESTIMATION OF KRILL AND WATER TURNOVER AND RESIDENCE TIMES

General Methodology

12. Krill flux and residence times were calculated following the methods detailed in Appendix D of SC-CAMLR-XII, Annex 4, and applied and developed in WG-Flux-94/15.

13. Inward flows into an area were termed as positive and outward flows as negative. The flux of krill V_D across a boundary of an area was expressed as the product of the profile of krill density along a boundary and the profile of water transport across that boundary.

$$V_D = \sum_{j=1}^{n} d_j f_j \qquad (1)$$

where n = number of intervals along a boundary

δ_j = density of krill in each interval (t km^{-3})

f_j = water transport across each interval (km^3 hr^{-1})

The krill influx was given by adding together the values for the inflow boundaries

$$V_I = \sum_{V_m > 0}^{b} V_m \tag{2}$$

where b is the number of boundaries, and the total efflux

$$V_o = \sum_{V_m < 0}^{b} V_m \tag{3}$$

Residence times (days) based on the inflow or outflow were calculated by dividing the krill biomass in the area by the relevant flux.

Inflow-based residence time

$$R_I = \frac{B}{V_I} \tag{4}$$

Outflow-based residence time

$$R_o = \frac{B}{V_o} \tag{5}$$

where B = krill biomass (tonnes).

14. Similar formulae were used to calculate water replacement times using water flows and water volume in the area in place of krill flux and biomass.

Calculation of Flux Rates and Residence Times in Subareas 48.1, 48.2 and 48.3

15. A number of small boxes were defined within subareas, using criteria such as data coverage and natural boundaries of oceanographic features and krill distribution (Figure 2).

16. Krill and water flux across each of the boundaries of the boxes defined in Figure 2 was calculated using programs developed by the Secretariat (WS-Flux-94/4). Krill density along each boundary and water speed normal to that boundary (i.e., directly across the boundaries) were calculated at interpolation points at intervals of 5 n miles along the boundary by weighted averaging of nearest data using the computer program described in WS-Flux-94/4. Weighting was by inverse distance and, for acoustic data, integration interval distance. For krill density calculations, all data

within a 30 n mile radius of an interpolation point were used, whereas for water flow the nearest nine data points were used.

17. This procedure was used for all acoustic data, the FRAM data and some of the CTD data. Some water flow vectors, however, were calculated directly from lines of CTD stations using linear interpolation because boundary effects rendered the inverse distance procedure unsuitable. Only those acoustic integration intervals taken during daylight hours were used for krill density calculations.

18. Krill density boundary vectors were calculated for FIBEX, SIBEX 1 and SIBEX 2 data separately. Water flow vectors were calculated for the FRAM data set and for the separate years of available geostrophic flow data. Figure 3 shows an example of krill density and flow vectors along a boundary (boundary 8, between boxes D and F). Krill and water flux across the boundary were calculated simply as the product of these vectors (t hr^{-1} and km^3 hr^{-1}).

19. Table 3 gives water flow rates across each of the boundaries in Figure 2, calculated using a number of data sets. The results of calculations of flux, using all the available combinations of acoustic data and hydrographic data are given in Table 4.

20. In order to calculate krill residence times, an estimate of the total biomass of krill in a box was required (paragraph 12). Similarly, for calculation of water residence times, total effective volume of water in a box was required.

- For krill, mean krill density (g m^{-2}) in each box was calculated using a simple mean of all acoustic density data in that box, weighting by integration distance (Table 5). For this reason, biomass estimates in Table 5 are slightly higher than those calculated by Trathan *et al*. (1992) using a transect-based method.

- For water, the relevant depth of the water column was taken to be 200 m for CTD derived data and 250 m for FRAM data.

21. Equations for calculation of residence times from a combination of boxes were developed (Attachment D) and used to calculate residence times for both water and krill for individual boxes (Table 6) and groups of boxes (Table 7).

Results

22. Generally, water flux values derived from the FRAM model were up to four times larger than those obtained from direct observations. This might reflect the incorporation of wind-induced surface currents to the model. The flux rates derived from observed data represent only the geostrophic component of the current field, based upon the given vertical density field. Additional analyses of the actual windfield data, as collected during the CTD measurements, should be undertaken to estimate the amount of wind-driven surface currents.

23. There was some seasonal variability in the estimates of water flow from the CTD data which was not resolved by the single time slice from FRAM. A further discrepancy was that the southwestward flowing Antarctic Coastal Current was not apparent in the FRAM data.

24. The only area of consistency between FRAM and observational data seems to be in the Bransfield Strait. Data derived from direct observations indicate that the inflow and outflow were balanced for this area. However, inflow and outflow were not balanced in the FRAM data. This might reflect the fact that water mass transport in the region is mostly confined to the upper hundreds of metres since the deep parts of the Bransfield Strait are blocked by ridges. These topographic features prevent deep reaching, consistent flow to the northeast and are not well described in the FRAM model.

25. Concerning inflow and outflow of individual boxes calculated from the FRAM data, boxes A, D, F and H might serve as examples where for the upper 200 m the influx of water masses is fairly consistent with the outflow.

RECOMMENDATIONS AND FUTURE WORK

26. Discussion of the significance of these results, recommendations to the Scientific Committee and suggestions for future work was left to the WG-Krill meeting.

CONCLUSION

27. The Chairman thanked all participants for a hard-working and successful workshop.

Table 1: Ancillary data on buoy speeds (derived from WS-Flux-94/8).

Section	Direction	Buoy Speed (cm/s)	FRAM Average Speed (cm/s)	Sub-section Coordinates
3	151.6°	-13.0	8.3	61 - 61.5 W
3	151.6°	11.4	12.1	59.9 - 61W
6	90°	20.3	7.9	61.05 - 61.2 S
7	0°	4.6	3.5	53.9 - 54.2 W
7	0°	-12.9	2.5	53 - 53.9 W
14	0°	10.3	0.9	51 - 51.2 W
14	0°	6.4	-2.2	49.9 - 51 W

Table 2: Areas and boundaries for the regions shown in Figure 4.

Region	Boundary Sections	Area (km^2)
A	0, 2, 3b, 3	39 466
B	1, 2, 4	31 106
C	4, 5, 10	30 465
K	3a, 3b, 5, 6	45 739
D	6, 7, 8, 9	40 759
E	9, 10, 11, 12	22 206
F	8, 12, 15, 13, 14	56 448
G	t1, t2, t3	30 343
H	t3, 22, 24, 25, 23, 21	70 852
I	24, 26, 28, 27	50 149
J	31, 32, 33, 34	34 452

Table 3: Water flow rates (cm sec^{-1}) across boundaries shown in Figure 2, from the FRAM data set, a number of hydrographic datasets (CTD samples) and iceberg track data. Negative flows are in a direction diametrically opposite to that shown.

Section	Distance (n miles)	Flow Direction	FRAM	CTD 1986	CTD 1987	CTD 1988	CTD 1990	CTD 1992	Iceberg
0	80	64.0	8.1	1.7	0.1		5.2		
1	50	64.0	3.9	-1.1	-0.1		-0.2		
2	140	59.3	0.2				0.2		
3	150	151.9	0.3						
3a	185	61.3	1.4						
3b	75	68.7	8.8						
4	80	70.9	7.7		6.8		7.3		
5	35	0	5.6				2.6		
6	120	90	8.6	3.8	4.4		4.8		
7	100	0	3.8						5.5
8	120	90	11.3	2.3			0.4		3.1
9	95	0	6.8				0.1		9.9
10	50	90	3.1	6.0			7.1		
11	55	0	5.2						7.0
12	70	90	0.3				1.3		3.3
13	190	90	7.2						4.3
14	90	0	1.6						5.7
15	80	0	1.6						7.3
t1	190	0	2.8						5.7
t2	215	65.4	-1.2						
t3	90	90	3.2			5.0			5.6
21	120	90	8.9						2.8
22	100	0	-2.6						9.5
23	90	0	0.4						13.0
24	110	90	9.7			3.2		1.6	3.4
25	95	90	4.9					1.9	5.3
26	130	0	6.7						8.3
27	120	0	3.2						5.0
28	110	90	5.9			3.1			3.5
31	40	90	-2.8						
32	125	0	3.9						9.1
33	95	90	-5.9						5.5
34	55	180	-2.8						

Table 4: Apparent krill flux and water flow rates across sections for various combinations of krill survey and oceanographic data sets. Negative fluxes are in a direction diametrically opposite to that shown.

Section	Data Set	Direction (°)	Krill Flux (tonnes h^{-1})	Water Flux (km^3h^{-1})
0	SIBEX 2*FRAM	64.0	80.8	8.7
	SIBEX 2*G86		17.4	1.8
	SIBEX 2*G87		1.0	0.2
	SIBEX 2*G90		52.7	5.5
1	SIBEX 2*FRAM	64.0	30.6	2.6
	SIBEX 2*G86		-10.7	-0.7
	SIBEX 2*G87		-3.0	-0.1
	SIBEX 2*G90		-4.5	-0.1
2	SIBEX 1*FRAM	329.3	43.2	-0.4
	SIBEX 1*G90		-8.9	-0.4
	SIBEX 2*FRAM		-7.5	-0.4
	SIBEX 2*G90		-15.4	-0.4
3	FIBEX*FRAM	331.9	1.3	-0.5
	SIBEX 2*FRAM		16.7	-0.5
3a	FIBEX*FRAM	331.3	83.1	-3.3
	SIBEX 1*FRAM		-39.1	-3.3
	SIBEX 2*FRAM		-28.5	-3.3
3b	FIBEX*FRAM	68.7	664.1	8.8
	SIBEX 1*FRAM		861.1	8.8
	SIBEX 2*FRAM		195.1	8.8
4	FIBEX*FRAM	70.9	6005.4	8.2
	FIBEX*G87		3787.6	7.3
	FIBEX*G90		4833.9	7.8
	SIBEX 1*FRAM		206.7	8.2
	SIBEX 1*G87		230.5	7.3
	SIBEX 1*G90		234.1	7.8
	SIBEX 2*FRAM		530.5	8.2
	SIBEX 1*G87		324.5	7.3
	SIBEX 2*G90		378.8	7.8
5	FIBEX*FRAM	0	511.4	2.6
	FIBEX*G90		151.3	1.2
	SIBEX 1*FRAM		18.0	2.6
	SIBEX 1*G90		12.9	1.2
	SIBEX 2*FRAM		168.5	2.6
	SIBEX 2*G90		94.2	1.2
6	FIBEX*FRAM	90.0	619.7	13.8
	FIBEX*G86		980.2	6.0
	FIBEX*G87		1309.2	7.1
	FIBEX*G90		1438.0	7.6
	SIBEX 1*FRAM		93.0	13.8
	SIBEX 1*G86		32.4	6.0

Table 4 (continued)

Section	Data Set	Direction (°)	Krill Flux (tonnes h^{-1})	Water Flux (km^3h^{-1})
	SIBEX 1*G87		38.9	7.1
	SIBEX 1*G90		38.2	7.6
	SIBEX 2*FRAM		312.0	13.8
	SIBEX 2*G86		166.3	6.0
	SIBEX 2*G87		213.2	7.1
	SIBEX 2*G90		215.5	7.6
7	FIBEX*FRAM	0	1007.6	5.1
	SIBEX 1*FRAM		50.8	5.1
	SIBEX 2*FRAM		58.7	5.1
8	FIBEX*FRAM	90.0	3556.1	18.1
	FIBEX*G86		741.8	3.7
	FIBEX*G90		153.0	0.6
	SIBEX 1*FRAM		0	18.1
	SIBEX 1*G86		0	3.7
	SIBEX 1*G90		0	0.6
	SIBEX 2*FRAM		0	18.1
	SIBEX 2*G86		0	3.7
	SIBEX 2*G90		0	0.6
9	FIBEX*FRAM	0	3826.3	8.7
	FIBEX*G90		43.1	0.1
	SIBEX 1*FRAM		26.3	8.7
	SIBEX 1*G90		0.4	0.1
	SIBEX 2*FRAM		251.4	8.7
	SIBEX 2*G90		2.2	0.1
10	FIBEX*FRAM	90.0	1462.1	2.1
	FIBEX*G87		3790.5	5.6
	FIBEX*G90		4932.9	6.7
	SIBEX 1*FRAM		8.4	2.1
	SIBEX 1*G87		28.7	5.6
	SIBEX 1*G90		34.8	6.7
	SIBEX 2*FRAM		82.4	2.1
	SIBEX 2*G87		210.6	5.6
	SIBEX 2*G90		258.0	6.7
11	FIBEX*FRAM	0	2538.3	3.8
	SIBEX 1*FRAM		33.8	3.8
	SIBEX 2*FRAM		153.1	3.8
12	FIBEX*FRAM	90.0	172.2	0.3
	FIBEX*G90		652.0	1.3
13	FIBEX*FRAM	90.0	2566.2	18.3
14	FIBEX*FRAM	0	204.4	1.9
15	FIBEX*FRAM	0	78.2	1.7

Table 4 (continued)

Section	Data Set	Direction (°)	Krill Flux (tonnes h^{-1})	Water Flux (km^3h^{-1})
t1	FIBEX*FRAM	0	449.8	7.1
t2	FIBEX*FRAM	335.8	1458.0	3.4
t3	FIBEX*FRAM	90.0	2546.7	3.9
	FIBEX*G88		3969.1	5.6
21	FIBEX*FRAM	90	1712.8	14.3
	FIBEX*G88		354.6	2.7
22	FIBEX*FRAM	180.0	2554.9	3.5
23	FIBEX*FRAM	0	6596.9	0.5
24	FIBEX*FRAM	90.0	13308.7	14.2
	FIBEX*G88		3052.0	4.7
	FIBEX*G92		2074.6	2.4
25	FIBEX*FRAM	90.0	11406.3	6.2
	FIBEX*G92		5295.9	2.4
26	FIBEX*FRAM	0	1564.3	11.7
27	FIBEX*FRAM	0	3116.9	5.2
28	FIBEX*FRAM	90.0	1898.2	8.6
	FIBEX*G88		1322.9	4.6
31	FIBEX*FRAM	270.0	179.6	1.5
32	FIBEX*FRAM	0	1002.3	6.6
33	FIBEX*FRAM	270.0	1889.1	7.5
34	FIBEX*FRAM	0	1553.8	2.1

Table 5: Biomass estimates for the regions in Figure 2 from the various surveys.

Region	Biomass from Survey (000s tonnes)		
	FIBEX	SIBEX 1	SIBEX 2
A	54	722	116
B	3 502	262	187
C	2 178	226	525
K	1 924	155	229
D	7 848	107	274
E	2 531	50	162
F	1 907	-	-
G	1 764	-	-
H	10 265	-	-
I	2 495	-	-
J	1 725	-	-

Table 6: Apparent krill and water retention times in the regions based on both influx and efflux rates, for various combinations of survey and oceanographic data sets.

Region	Data Set	Water Retention Time (days)		Krill Retention Time (days)	
		Influx	Efflux	Influx	Efflux
A	SIBEX 2*FRAM	44.7	44.8	60.0	22.1
B	SIBEX 2*FRAM	108.2	39.7	205.3	14.7
C	FIBEX*FRAM	38.8	67.1	15.1	46.0
	SIBEX 1*FRAM			45.6	355.7
	SIBEX 2*FRAM			41.3	87.2
	FIBEX*G90	32.4	32.2	18.8	17.9
	SIBEX 1*G90			40.2	197.3
	SIBEX 2*G90			57.8	62.1
K	FIBEX*FRAM	32.3	34.5	68.2	114.1
	SIBEX 1*FRAM			7.0	69.5
	SIBEX 2*FRAM			24.4	30.6
E	FIBEX*FRAM	39.2	25.8	26.4	26.4
	SIBEX 1*FRAM			49.7	---
	SIBEX 2*FRAM			28.7	---
	FIBEX*G90	---	170.6	---	151.8
D	FIBEX*FRAM	18.9	18.3	73.6	71.7
	SIBEX 1*FRAM			37.4	87.8*
	SIBEX 2*FRAM			20.3	195.1*
	FIBEX*G90	44.0	---	220.8	---
	SIBEX 1*G90			115.5	---
	SIBEX 2*G90			52.6	---
F	FIBEX*FRAM	29.2	29.1	20.9	28.7
G	FIBEX*FRAM	44.6	43.7	163.4	18.4
H	FIBEX*FRAM	33.3	36.1	31.9	17.3
I	FIBEX*FRAM	26.9	25.8	6.3	30.0
J	FIBEX*FRAM	37.7	44.2	20.9	60.8

* No krill density estimates were available on section 8 for SIBEX 1 and 2 (see second page of Table 4, column 4). Therefore these retention times are probably biased upwards.

Table 7: Apparent krill and water retention times in combined regions based on both influx and efflux rates, for various combinations of survey and oceanographic data sets.

Combined Regions	Data Set	Water Retention Time (days)		Krill Retention Time (days)	
		Influx	Efflux	Influx	Efflux
ABKCDE	SIBEX 2*FRAM	115.5	93.0	212.7	---
KDCEF	FIBEX*FRAM	79.0	80.4	73.6	176.9
KCDE	FIBEX*FRAM	60.2	61.7	65.5	125.2
	SIBEX 1*FRAM			19.7	---
	SIBEX 2*FRAM			54.7	---
HI	FIBEX*FRAM	46.1	47.6	32.2	35.8

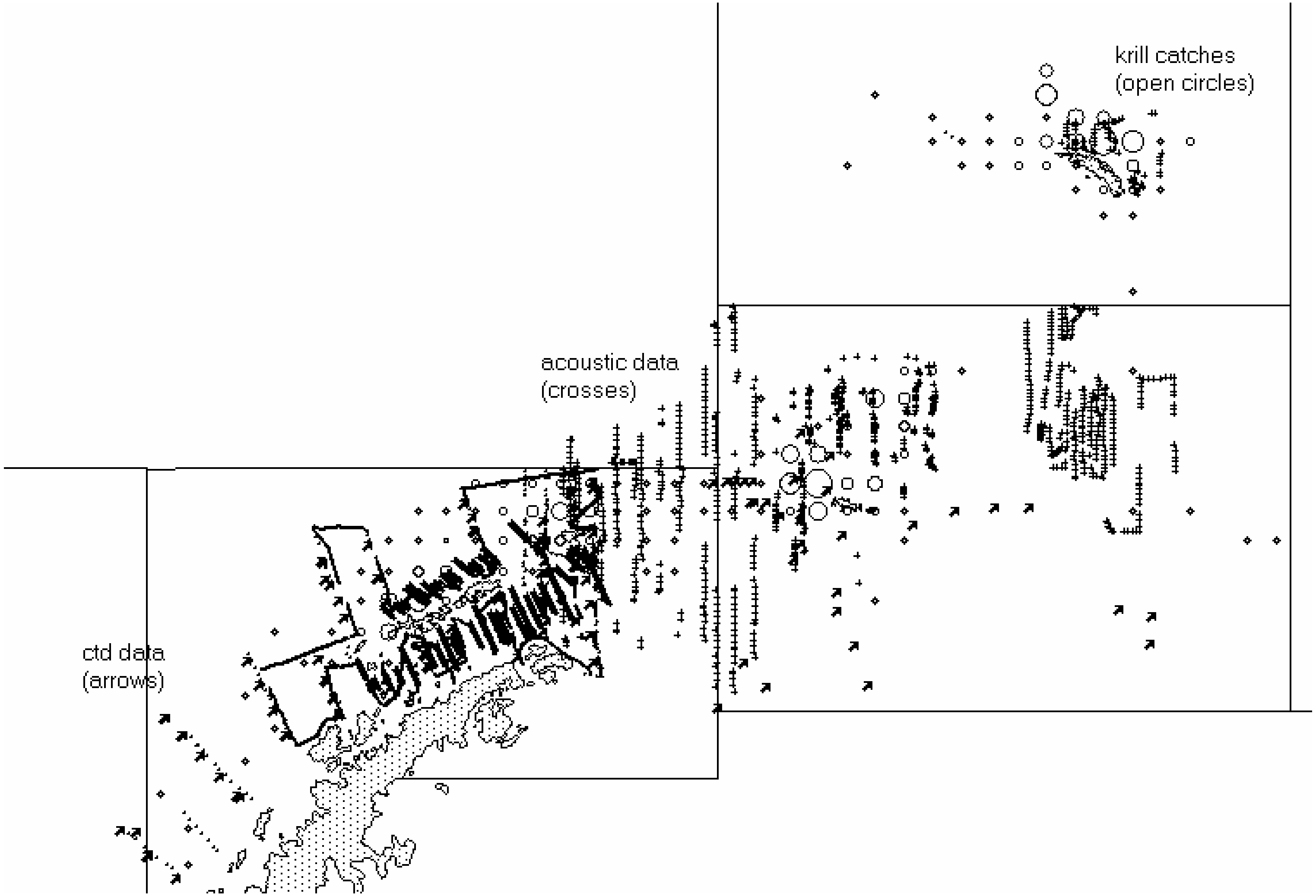

Figure 1: Acoustic CTD data available to the workshop overlaid with the distribution of krill catches over the last 10 years.

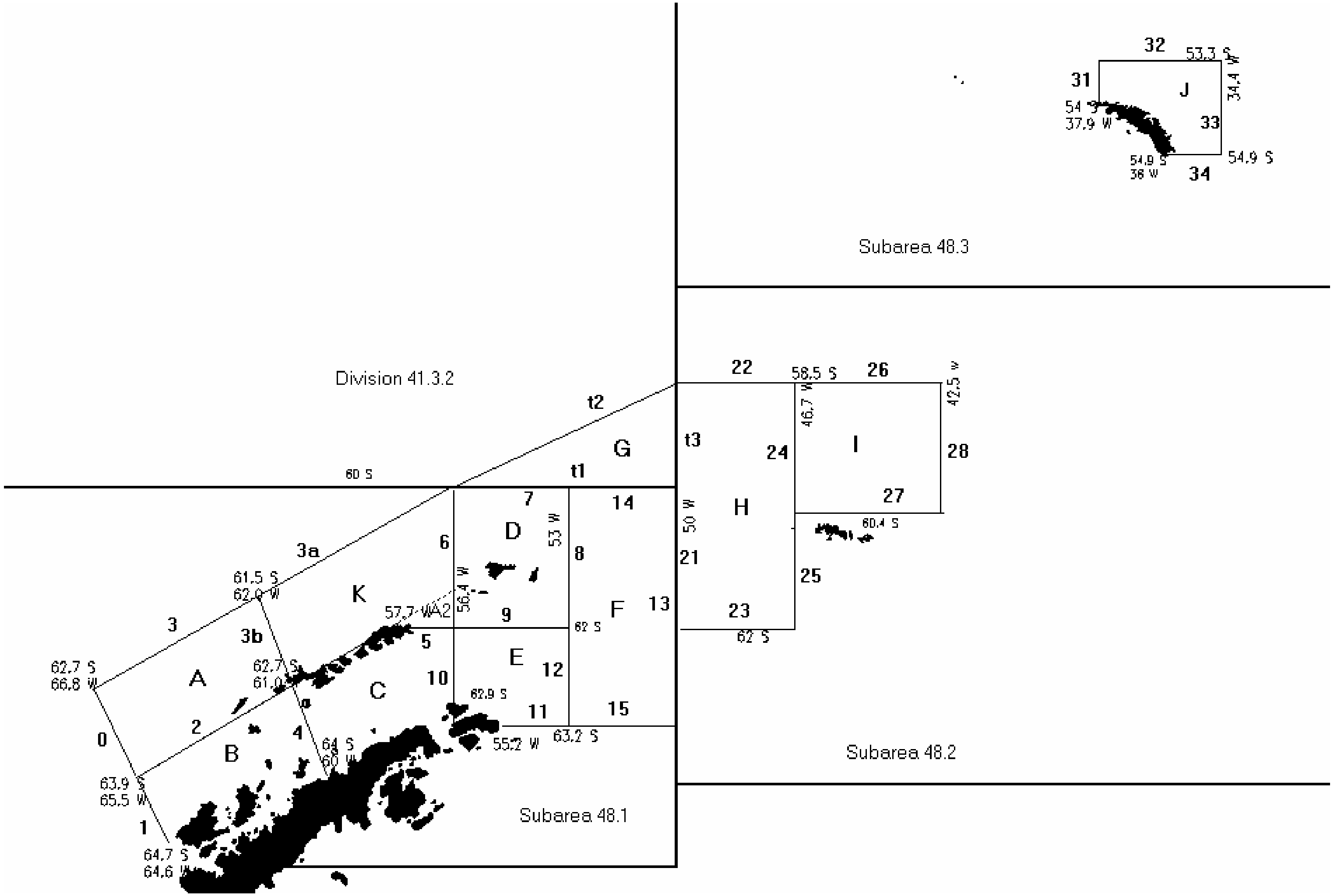

Figure 2: Boxes and boundaries (bold) defined for krill and water flux calculations. Boundary positions are marked.

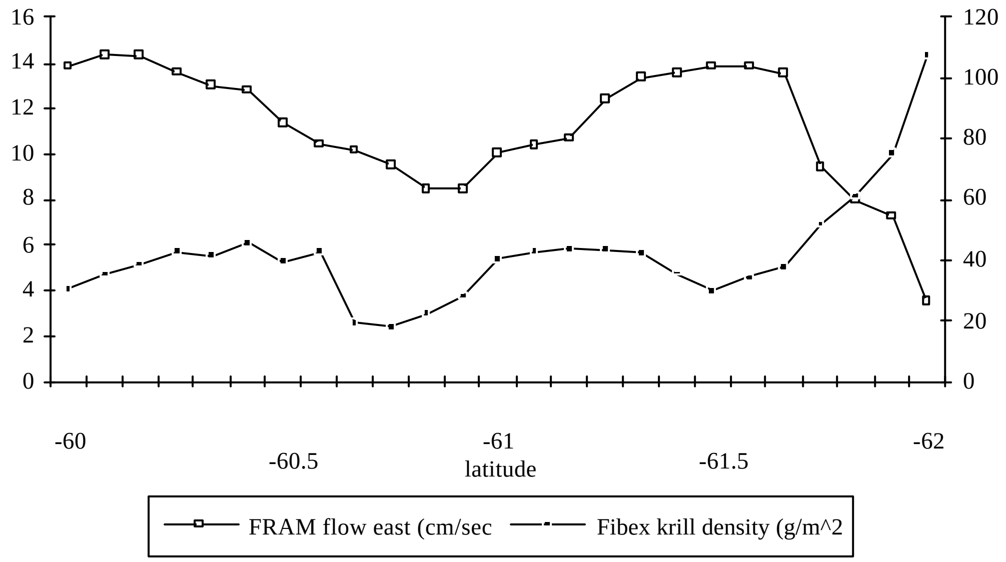

Figure 3: Example of water flow and krill density calculated along a boundary (boundary 8). These data were combined to yield a total flux for that boundary. Left hand y-axis is cm/sec.

ATTACHMENT A

AGENDA

Workshop on Evaluating Krill Flux Factors
(Cape Town, South Africa, 21 July to 23 July 1994)

1. Introduction
   (i) Appointment of Chairman
   (ii) Appointment of Rapporteurs
   (iii) Adoption of the Agenda

2. Review of Data and Analyses
   (i) Krill Acoustic Data Specified in Appendix D (SC-CAMLR-XII, Annex 4)
   (ii) FRAM Oceanographic Data Specified in Appendix D (SC-CAMLR-XII, Annex 4)
   (iii) Primary Oceanographic Data
   (iv) Additional Data and Analyses

3. Composite Flux Analysis
   (i) Subarea 48.1
   (ii) Subarea 48.2
   (iii) Subarea 48.3

4. Implications and Recommendations to WG-Krill

5. Close of Meeting.

ATTACHMENT B

LIST OF PARTICIPANTS

Workshop on Evaluating Krill Flux Factors
(Cape Town, South Africa, 21 July to 23 July 1994)

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ATTACHMENT C

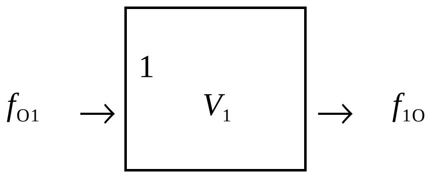
LIST OF DOCUMENTS

Workshop on Evaluating Krill Flux Factors
(Cape Town, South Africa, 21 July to 23 July 1994)

WS-Flux-94/1	AGENDA
WS-Flux-94/2	LIST OF PARTICIPANTS
WS-Flux-94/3	LIST OF DOCUMENTS
WS-Flux-94/4	ACOUSTIC DATA FOR THE 1994 KRILL FLUX WORKSHOP Secretariat
WS-Flux-94/5	USE OF CURRENT VELOCITY DATA FROM FRAM TO INVESTIGATE THE LARGE SCALE TRANSPORT OF KRILL IN THE SCOTIA SEA E.J. Murphy (UK)
WS-Flux-94/6	LARGE SCALE CIRCULATION IN THE SOUTH ATLANTIC: ESTIMATES FROM GIANT ICEBERG DRIFT RATES P.N. Trathan and C. Symon (UK)
WS-Flux-94/7	COMPARISON OF GEOSTROPHIC VELOCITIES FROM SUBAREA 48.1 William K. de la Mare (Australia)
WS-Flux-94/8	REFERENCE MATERIALS ON STATISTICAL AREA 48 FOR KRILL FLUX WORKSHOP Mikio Naganobu (Japan)
WS-Flux-94/9	STREAM LINES IN THE FRAM VELOCITY FIELD: SPEEDS AND DIRECTIONS FROM PASSIVE TRACERS E.J. Murphy (UK)
WS-Flux-94/10	TRACER TRAJECTORIES FROM THE WESTERN SHELF OF SOUTH GEORGIA: SHIP DISPLACEMENT DATA E.J. Murphy, I. Everson and C. Goss (UK)

RETENTION/RESIDENCE TIMES

1-BOX SYSTEM - Example



V_1 = volume (e.g., water volume) in box 1 (e.g., km^3)

f_{O1} = input from 'outside' into box 1 (e.g., in km^3/day)

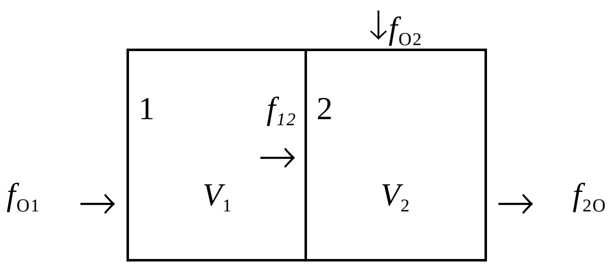
f_{1O} = outflow from box 1 to the 'outside' (e.g., in km^3/day)

The subscript 'O' refers to 'outside'

T_1 = turnover for box 1 = $\dfrac{f_{O1}}{V_1}$

r_1 = residence time in box 1 = $\dfrac{V_1}{f_{O1}}$ (e.g., in days)

2-BOX SYSTEM - Example



Vs and fs as above: all fs > 0 (if $f_{ij} < 0 \Rightarrow f_{ji} = -f_{ij}$ to get a positive flow)

r_1 = residence time in box 1 = $\dfrac{V_1}{f_{O1}}$

r_2 = residence time in box 2 = $\dfrac{V_2}{f_{12} + f_{O2}}$

If we ignore the subdivision then the overall R (residence time) is:

$$R = \frac{(V_1 + V_2)}{f_{O1} + f_{O2}} = \frac{V_1}{f_{O1} + f_{O2}} + \frac{V_2}{f_{O1} + f_{O2}}$$

Can we write R in terms of r_1 and r_2?

Yes,

$$R = \frac{V_1}{f_{O1} + f_{O2}} \cdot \left(\frac{f_{O1}}{f_{O1}} \right) + \frac{V_2}{f_{O1} + f_{O2}} \cdot \left(\frac{f_{12} + f_{O2}}{f_{12} + f_{O2}} \right)$$

which can be re-organised as:

$$\begin{aligned} R &= \frac{V_1}{f_{O1}} \cdot \left(\frac{f_{O1}}{f_{O1} + f_{O2}} \right) + \frac{V_2}{f_{12} + f_{O2}} \cdot \left(\frac{f_{12} + f_{O2}}{f_{O1} + f_{O2}} \right) \\ &= r_1 \underbrace{\left(\frac{f_{O1}}{f_{O1} + f_{O2}} \right)}_{\text{call this } w_1} + r_2 \underbrace{\left(\frac{f_{12} + f_{O2}}{f_{O1} + f_{O2}} \right)}_{\text{call this } w_2} \\ &= r_1 \cdot w_1 + r_2 \cdot w_2 \end{aligned}$$

where the w_1, w_2 are called pooling weights.

Note:

(i) any weight can be less than or greater than 1 (e.g., if $f_{12} > f_{O1}$ then w_2 will be > 1);

(ii) $R = r_1 + r_2$ only if $w_1 = 1$ and $w_2 = 1$; i.e. residence times in the boxes can only be added directly, that is unweighted, when $f_{O2} = 0$ and $f_{12} = f_{O1}$.

N-BOX SYSTEM: GENERAL CASE

$$R = \sum_{i=1}^{N} r_i \cdot w_i$$

where each $r_i = V_i \Big/ \sum_{j=0}^{N} f_{ji}$

and $w_i = \sum_{j=0}^{N} f_{ji} \Big/ \sum_{j=1}^{N} f_{Oj} \quad = \quad \dfrac{\text{all inputs to box } i \text{ (from 'anywhere')}}{\text{all inputs to the system from OUTSIDE (N boxes)}}$