DATA ON KRILL (*EUPHAUSIA SUPERBA* DANA) CONSUMPTION BY COASTAL FISHES IN DIVISION 58.4.2 (KOSMONAVTOV AND SODRUZHESTVA SEAS)

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Abstract

Current estimates of the level of krill consumption (*Euphausia superba*) are based on data obtained from the Atlantic sector which have then been extrapolated over all of Antarctica. According to these calculations the entire amount of krill consumed is between 166 and 450 million tonnes; of this amount fish consume from 30 to 32 million tonnes (Lubimova, Shust, 1980 and Shust, 1987). However these extrapolated values of krill consumption by fish and other species may differ significantly from those for specific areas. Localised assessments of krill consumption have thus far only been carried out for the Scotia and Lazarev Seas (Kock, 1985; Miller *et al.*, 1985). Assessments contained in this paper are based on results of research conducted in the Sodruzhestva and Kosmonavtov Seas over many years by the YugNIRO institute. Data obtained from trawl and acoustic surveys as well as on fish feeding patterns and krill production were used in the calculations. Assessments of krill consumption are based on calculations made for individual fish species taking into account their distribution in the particular study area of Antarctica. Total fish stock was calculated for a depth range of 100 to 500 metres in waters between 30 and 80°E. Krill consumption was estimated for summer only (December to April). The assessments obtained indicate that if total fish biomass is 551 300 tonnes, fish will consume 960 000 tonnes of krill. Given the total krill biomass in the study area it is concluded that fish consume from 9 to 18% of annual krill production.

Résumé

Les estimations actuelles du niveau de consommation de krill (*Euphausia superba*) sont fondées sur des données provenant du secteur atlantique, qui ont ensuite été extrapolées sur la totalité de l'Antarctique. Ces calculs nous portent à croire que la quantité totale de krill consommée se situe entre 166 et 450 millions de tonnes, dont 30 à 32 sont consommées par des poissons (Lubimova and Shust, 1980; Shust, 1987). Cependant, il est possible que ces valeurs extrapolées de la consommation de krill par des poissons ou d'autres espèces diffèrent grandement de celles des zones spécifiques. Les évaluations localisées de la consommation de krill n'ont été effectuées, jusqu'à maintenant, que pour les mers de la Scotia et de Lazerev (Kock, 1985; Miller et al., 1985). Les évaluations de cette communication sont tirées des résultats de recherches menées par l'institut YugNIRO dans les mers Sodruzhestva et Kosmonavtov sur plusieurs années. Les données provenant des campagnes par chalutages et acoustiques, de même que les données sur les rythmes alimentaires des poissons et la production de krill ont servi aux calculs. Les évaluations de la

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espèces de poissons individuelles, en tenant compte de leur répartition dans la zone d'étude donnée en Antarctique. Le stock total de poissons a été calculé pour une échelle de profondeur de 100 à 500 mètres dans les eaux situées entre 30 et 80°E. La consommation de krill n'a été évaluée que pour l'été (de décembre à avril). D'après les évaluations, si la biomasse totale de poisson s'élève à 551 300 tonnes, les poissons consommeront 960 000 tonnes de krill. Vu la biomasse totale de krill dans la zone d'étude, nous pouvons conclure que le poisson consomme 9 à 18% de la production annuelle de krill.

Резюме

Имеющиеся до настоящего времени оценки потребления Антарктического криля, *Euphausia superba*, различными видами-консументами были основаны на данных, полученных для Атлантического сектора и экстраполированных на всю акваторию Антарктики. По этим расчетам общее количество потребляемого криля находится на уровне 166-450 млн тонн, а на долю рыб приходится до 30-32 млн тонн криля от этого количества (Любимова, Шуст, 1980 и Шуст, 1987). Однако для конкретных регионов Антарктики действительные величины потребления криля рыбами и другими видами-консументами могут значительно отличаться от этих экстраполированных величин. Региональные оценки потребления криля были выполнены до сих пор только для морей Скотия и Лазарева (Kock, 1985, Miller *et al.*, 1985). Изложенные в настоящей работе оценки потребления криля рыбами основаны на результатах многолетних исследований, проведенных институтом ЮгНИРО в морях Содружества и Космонавтов. В расчетах использовались данные траловых и акустических съемок и материалы по питанию рыб и продукции криля. Оценка потребления криля основана на расчетах по отдельным видам рыб с учетом их распространения в исследуемом районе Атнарктики. Общий запас рыб был расчитан для диапазона глубин 100-500 м в водах между 30° и 80°в.д. Оценка потребления криля была произведена только для летнего сезона (декабрь-апрель). Полученные оценки показывают, что при общей биомассе рыб равной 551 300 тонн они потребляют 960 000 тонн криля. Принимая во внимание общую биомассу криля в исследуемом районе, делается вывод, что рыбы могут потреблять до 9-18% от его годовой продукции.

Resumen

Los cálculos actuales del nivel de consumo de krill (*Euphausia superba*) se basan en los datos obtenidos del sector Atlántico que han sido extrapolados sobre toda la Antártida. De acuerdo con estos cálculos, la cantidad total de krill consumido es entre 166 y 450 millones de toneladas; de esta cantidad, los peces consumen entre 30 y 32 millones de toneladas (Lubimova, Shust, 1980 y Shust, 1987). Sin embargo, estos valores extrapolados del consumo de krill por los peces y otras especies, podrían ser considerablemente distintos a aquellos de áreas

especies, podrían ser considerablemente distintos a aquellos de áreas específicas. Hasta ahora se han realizado evaluaciones locales del consumo de krill para los mares de Scotia y Lazarev solamente (Kock, 1985, Miller *et al.*, 1985). Las evaluaciones que aparecen en este documento se basan en los resultados obtenidos de investigaciones realizadas durante muchos años por el instituto YugNIRO en los mares de Sodruzhestva y Kosmonavtov. En los cálculos se ha utilizado la información obtenida de las prospecciones acústicas y de arrastre, así como de los patrones de alimentación de peces y de la reproducción del krill. Las evaluaciones del consumo de krill se basan en los cálculos hechos para especies individuales de peces, tomando en cuenta su distribución en el área de estudio de la Antártida. Se calculó la población total de peces para el rango de profundidad de 100 a 500 metros en las aguas entre 30 y 80°E. Solamente se calculó el consumo de krill durante el verano (diciembre a abril). Las evaluaciones obtenidas indican que si la biomasa total de peces es de 551 300 toneladas, los peces consumirán 960 000 toneladas de krill. Se concluye que, dada la biomasa total del krill en el área de estudio, los peces consumen de un 9 al 18% de la producción anual de krill.

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1. INTRODUCTION

In order to understand properly the fundamental patterns of the unique pelagic ecosystems in some Antarctic regions and to implement a rational regime of harvesting bio-resources, it is important to determine the level of krill consumption by its various predators. Previous assessments (Lubimova, Shust 1980; Laws 1985) gave values from 166 to 450 million tonnes for krill consumption, assuming that of this amount fish consumed 30 to 32 million tonnes. For the most part these figures are based on data obtained from the Atlantic sector of the Southern Ocean. In our view, for specific areas the ratio of krill consumption by fish and other consumers may be widely divergent from those values obtained by extrapolation for all Antarctic waters. Localised assessments have only been carried out for the Scotia (Kock, 1985) and Lazarev (Miller *et al.*, 1985) Seas. Such attempts have not been made for the Indian Ocean sector, more importantly for such locations as the Sodruzhestva and Kosmonavtov Seas. Moreover, Russian scientists have pointed out the possibility of the formation of various biotopes whose organisms (fish) have different levels of krill consumption (Trotsenko *et al.*, 1990) and the existence of independent faunistic macroplankton complexes in different parts of continental seas (Pakhomov, 1991).

This work is founded on the results of many years' research by YugNIRO in the Sodruzhestva and Kosmonavtov Seas and is perhaps the first attempt to assess the amount of krill consumed by fish in that area.

2. MATERIALS AND METHODS

Data on krill and fish stocks and biomass, diet composition, fish feeding rates and trophic relationships are used in this work. The mean krill stock size in the Sodruzhestva Sea (to the south of 65°30'S, between 60 and 80°E, area approximately 10^7 km^2) was calculated from census trawl and acoustic surveys from 1978 to 1990. Mean biomasses in certain areas, where fish biomass was observed to be high, were determined for 1978 to 1990. It should be noted that acoustic surveys in these areas were carried out over one to three days and, as a rule, where krill swarms were of a high density. Therefore the biomass values obtained are "instantaneous" and high in relation to the real average.

Information on biomass assessment methods used, survey designs, confidence intervals and krill trawls used is contained in the works of Bibik and Yakovlev (1990) and Bibik and Yakovlev (1991). These works also contain data on krill stocks in the Sodruzhestva Sea and biomass in the continental slope area 65 to 66°E. Krill biomass in the area 61 to 63° was calculated for the first time.

Mean krill stock size (biomass) in the Kosmonavtov Sea (area 8 x 10^4 km^2) was determined by averaging trawl-acoustic data for the three years from 1988 to 1990.

Data obtained by YugNIRO following experimental work on daily krill growth rates (0.0033 mm) were used to determine krill production (Samyshev 1986). Therefore the P/B coefficient for summer (December-April), when the amount of krill eaten by fish was calculated, equals 0.5. Given this coefficient and the long term average biomass for the Sodruzhestva and Kosmonavtov Seas (8 x 10^6 tonnes) seasonal krill production is 4 x 10^6 tonnes; 2.5 x 10^6 tonnes for the Sodruzhestva Sea and 1.5 x 10^6 tonnes for the Kosmonavtov Sea.

Serious difficulties arose during calculation of yearly krill production. The majority of scientists assume that an animal's growth ceases during winter (Aseev, 1983; Siegel, 1987 and Hosie *et al.*, 1988). In this case the seasonal coefficient and seasonal production may be proportional to their annual values. Using simulation methods, V.B. Tseitlin calculated the annual P/B coefficient to be 0.52 (Tseitlin, 1989), in other words close to the seasonal value determined from experiments.

There is also a theory that krill does not stop growing entirely in winter (Samyshev, 1991). According to this view, growth occurs not only from December to April, but also in the months leading up to this period (at least from October) when the days become lighter and krill can feed on algae in large polynyas as well as on cryophyte phytoplankton. Taking this into account, E.Z. Samyshev calculated the annual P/B coefficient to be 1.0 (Samyshev, 1991). In this case, yearly krill production in the study area would be 8 x 10^6 tonnes; 5 x 10^6 tonnes for the Sodruzhestva Sea and 3 x 10^6 tonnes for the Kosmonavtov Sea. Therefore, we assume that the minimum value of P/B coefficient should be 0.5 (seasonal production) and the maximum value 1.0 (yearly production).

Fish biomass on the outer shelf and the upper part of the continental slope was determined using the swept area method based on results of bottom and mid-water trawl hauls as well as acoustically, whereby swarm density has already been calculated using data from control hauls.

Stocks of Antarctic silverfish *Pleuragramma antarcticum* were assessed using the swept area method and only for pelagic aggregations. Standard commercial mid-water trawls 99.4m, 86.0m, 78/520m, 110/560 and 110/600m with fine-meshed nets were used (minimum mesh size in the codend - 20 mm). Trawl mouth openings ranged from 800 to 2 338 m^2; trawling speed was from 2.5 to 5 knots (3.5 knots on average). Overall, the results of more than 300 hauls were used. It should be noted that commercial fishing of *P. antarcticum* in Subarea 58.4 did not take place.

The biomass of bottom-dwelling fish on the banks of the Sodruzhestva and Kosmonavtov Seas was determined using trawl-acoustic survey data in swarms and bottom haul data for fish beyond these swarms. Trawls 33/64m, 45/48.4m, 41.7/39.6m had 80 mm mesh-size in the codend. The horizontal trawl opening was 21 to 24 metres and the trawling speed was 2.5 to 4.0 knots (an average of 3 knots).

The biomass of bottom-dwelling fish was calculated by stratum (Table 1). Data on area were kindly supplied to us by Dr Trofimov. In calculating biomass, note was taken of the

particular biotopes formed in various areas of the shelf and the different proportionality of species therein. Therefore the areas under study were divided into subareas with different biotopes of major species, largely for the sake of convenience (Trotsenko *et al.*, 1990). We tried to avoid averaging the available data which could have disguised or even led to the "disappearance" of some fish species and, consequently, their role in the functioning of the ecosystem.

Data on fish feeding were gathered during YugNIRO expeditions from 1983 to 1990. In total, the contents of 12 500 stomachs of 27 fish species were analysed. Fish were sampled from catches of commercial mid-water and bottom trawls operating at depths of 100 to 600 m, mainly from 200 to 400 m. These data are presented in Pakhomov (1989).

In order to assess fish diet, stations lasting from one to several days were carried out in the Kosmonavtov Sea above the Gunnerus Ridge from 7 to 10 February 1983; near Prince Olaf Land from 19 to 20 March 1987; at 67°50'S - 41°25'E from 23 to 24 March 1988 and at the bank located at 62°30'E in the Sodruzhestva Sea (Storegg Beach) from 4 to 10 March 1989, 8 to 10 February 1990 and 11 to 13 March 1990. Analysis of data and calculations of daily diets are presented in Pakhomov (1989) and Pakhomov and Tseitlin (1992). Other reference material on the daily food ration of *P. antarcticum* was also used (Gorelova and Gerasimchuk, 1981).

Calculation of krill consumption was carried out for summer only (five months from December to April). The values of mean daily diet of all fish species were taken from Pakhomov and Tseitlin (1992), except in the case of *Chaenodraco wilsoni*, in respect of which a slackening off in feeding was observed during spawning in December and January (Gerasimchuk and Trotsenko, 1988). Therefore, in calculating the seasonal diet of this species it was assumed that the average daily ration in December-January was 0.6% of body weight (Pakhomov and Tseitlin, 1991) and 2.5% of body weight in February-April (Pakhomov, 1989).

3. RESULTS

3.1 Kosmonavtov Sea

Food requirements of various species are given in Table 2 and in Table 3 for *C. wilsoni* on various banks. According to Table 2, total fish stocks are 295.6 $x10^3$ tonnes and the total consumption of krill over the summer is estimated at 515.4 x 10^3 tonnes. The main consumers of krill are *C. wilsoni* (62%) and *P. antarcticum* (33.5%). Moreover, according to Table 3, *C. wilsoni* primarily consumes krill where dense swarms form over localised banks (52%).

The total mean stock size of krill in the Kosmonavtov Sea is estimated at 3.0 x 10^6 tonnes. Applying the values for P/B coefficients presented above gives a minimum seasonal production of 1.5 x 10^6 tonnes and a maximum value of 3.0 x 10^6 tonnes. In this case the total value of krill consumption by fish comprises 34% of seasonal production and 17% of yearly production.

3.2 Sodruzhestva Sea

Over the period December to April, assessment of krill consumption by fish was carried out both for the entire sea as well as individual areas (underwater rises) with high ichthyomass levels, where krill was the main component of fish diets.

3.3 Bank "62°30'E"

Of the 30 000 tonne fish stock in this area (Zaitsev *et al.*, 1990) 79% comprised *C. wilsoni* and 20% were *Trematomus eulepidotus*. The amount of krill consumed from January to April 1990 was calculated using data on the daily ration of the larger fish species inhabiting this area as well as the contents of their stomachs. According to these calculations the amount of krill consumed over the summer period in this area was 109.03 x 10^3 tonnes.

Instantaneous krill biomass in the bank area (between 61° and 63°E) was 0.65 ± 0.12 x 10^6 tonnes in February and 0.13 ± 0.03 x 10^6 tonnes in March. Daily production for the two months was 2.1 and 0.4 x 10^3 tonnes respectively.

Daily krill requirements for fish were 1.5 x 10^3 tonnes at the beginning of the season and 0.36 x 10^3 tonnes at the end. Thus in January-February, fish consumed in one day up to 68% of daily krill production in this localised area. The index of stomach fullness for fish (6.8 to 7.5% of body mass) indicates that krill had been feeding intensely during the same period. Krill comprised 81 to 83% of stomach contents. The daily krill requirement for fish in March was 90% of daily krill production. This would seem to explain the drop in feeding rates (mean index of stomach fullness was from 2.0 to 6.9%) and a switch from *E. superba* to *E. crystallorophias* as the main dietary component (up to 65% body weight).

3.4 Bank "65°10'E" (Table 4)

Total fish stock size was 4.6 x 10^3 tonnes, 99% of which was comprised of *T. eulepidotus*. Preliminary calculations indicate that from January to April fish consumed 10.6 x 10^3 tonnes of krill on this rise. Krill biomass in this area (between 65° and 66°) varied from 0.2 to 0.3 x 10^6 tonnes. Total daily krill production was 0.8 x 10^3 tonnes. The daily krill requirements for fish was calculated to be 0.09 x 10^3 tonnes (about 11% of daily production).

Favourable oceanic conditions were reflected by a high degree of stomach fullness (4.2 to 7.6% body weight).

3.5 Prydz Bay (Table 5)

P. antarcticum stocks in Prydz Bay have varied over the years from 17.5 to 85 x 10^3 tonnes. Seasonal consumption of krill by this species ranges from 26 to 128 x 10^3 tonnes and it is able to consume from one to 13% of yearly krill production. Data contained in Table 5 indicate that, in addition to several other key factors, the *P. antarcticum* population contributed significantly to the decrease of krill biomass in 1986 when it consumed more than a tenth of yearly krill production.

3.6 Sodruzhestva Sea in General (Table 6)

The total fish stock in the Sodruzhestva Sea is estimated at 255.7 x 10^3 tonnes and seasonal krill consumption at 444.7 x 10^3 tonnes. Approximately 18% of seasonal or 9% of yearly krill production is consumed by all fish over the summer season.

4. DISCUSSION AND CONCLUSIONS

We have obtained a value of approximately one 1 x 10^6 tonnes, or 25% of seasonal and 12% of yearly production, for the amount of krill consumed by coastal fishes in the Kosmonavtov and Sodruzhestva Seas during summer (December to April).

Our estimate for krill consumption is quite high when one considers that it was calculated for the summer season alone and only for coastal fishes of a commercial size. Assuming that these fish continue to feed in the winter, the actual level of consumption will obviously be much higher.

In conclusion, we would like to emphasise strongly the regional nature of the estimates presented. For this reason we believe it would be absolutely improper to link our results to other areas of Antarctica. It must also be pointed out that in some areas of the Antarctic, various groups of organisms could be the primary consumers of *E. superba.* It is entirely possible that in Prydz Bay (Sodruzhestva Sea), the main krill consumers are *P. antarcticum, T. eulepidotus* and whales (or seals), while they might be penguins in areas adjacent to the Antarctic Peninsula and crab-eater seals in the Ross Sea. The environment of the Antarctic is highly diverse. Therefore a great deal remains to be done in order to obtain a realistic value for the amount of krill eaten by all possible groups of consumers. Solving this problem would be greatly assisted by the combined efforts of Russian, Australian, South African and Japanese scientists in carrying out, under the aegis of CCAMLR, regular ecosystem monitoring in the Sodruzhestva Sea and adjacent areas.

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Table 1: Area of depth strata between 30° and 80° and the number of hauls used to estimate the biomass of bottom-dwelling fish.

Depth Range (metres)	100 to 200	200 to 300	300 to 500
	Kosmonavtov Sea		
Number of Hauls	2	250	22
Area (miles^2)	2774	4020	3777
	Sodruzhestva Sea		
Number of Hauls	10	88	52
Area (miles^2)	6654	5162	12061

Table 2: Consumption of Antarctic krill by coastal fishes in the Kosmonavtov Sea (30°-50°E) from December to April. Calculated for the depth range 100 to 500 metres.

Species	Stock Size (tonnes)	Seasonal Diet (body mass)	Percentage of Krill by Weight in Stomach	Krill Consumption
Chaenodraco wilsoni	137090	2.61	90	322024
Trematomus eulepidotus	1028.5	3.0	50	1543
Pleuragramma antarcticum	128046	1.5	90	172862
Trematomus hansoni	7593.5	5.25	12	4784
Chionodraco hamatus	3200	2.4	3	230
Cryodraco antarcticus	1143	3.3	1	1
Lepidonotothenia kempi	9987	5.25	20	10486
Dissostichus mawsoni	711	5.25	2	75
Cygnodraco mawsoni	700	1.5	5	53
Trematomus centronotus	522	3.0	20	313
Gymnodraco acuticeps	277	6.0	3.5	58
Others: *Neopagetopsis ionah, T. nicolai, Histiodraco velifer, Pogonophrine scotti, Bathyraja* sp. *et al.*	5279	3.75	2-50, on average 15	2969
Total	295577	2.32	82.2	515398

Table 3: Krill consumption by *Chaenodraco wilsoni* on various banks in the Kosmonavtov Sea.

Bank Longitude	Fish Stock (x 10^3 tonnes)	Krill Consumption by Periods (x 10^3 tonnes)	Total Krill Consumption over Summer (x 10^3 tonnes)
40°40'E	9	21.2	21.2
	9.4(XII-I)*	3.0	
41°10'E	30(II-III)*	40.5	52.3
	13(IV)*	8.8	
41°40'E	9	21.2	21.2
42°10'E	4.6	10.8	10.8
42°50'E	22	51.7	51.7
43°10'E	10.5	24.7	24.7
44°30'E	30	70.5	70.5
45°30'E	7	16.4	16.4
Total krill consumption			268.8

* months

Table 4: Antarctic krill consumption by fish on banks 62°30'E and 65°10'E in the Sodruzhestva Sea during January to April 1990.

Fish Species	Bank '62°30'E'				Bank '65°10'E'			
	Stock (tonnes)	Seasonal Diet (body mass)	Percentage of Krill in Food	Krill Consumption (tonnes)	Stock (tonnes)	Seasonal Diet (body mass)	Percentage of Krill in Food	Krill Consumption (tonnes)
C. wilsoni	23730	3.438* / 2.76	81* / 34	67236* / 22268; 89504	-	-	-	-
C. hamatus	90	1.8	48	78	-	-	-	-
C. antarcticus	30	2.04	1	1	-	-	-	-
N. ionah	90	3.0	40	108	-	-	-	-
T. eulepidotus	5910	3.82 / 0.89	83 / 16	18738 / 842; 19580	4573	3.0	77	10564
T. hansoni	90	4.2	12	45	5	4.2	12	2
D. mawsoni	60	4.2	3	8	-	-	-	-
Total	3000			109324	4578			10566

* Nominator - data for January-February; denominator - data for March-April.

Table 5: Krill consumption by *Pleuragramma antarcticum* in Prydz Bay (seasonal diet was 1.5 of body mass; krill comprised 90% of food)

Year	*P. antarcticum* Stock (x 10^3 tonnes)		Antarctic Krill Biomass between 68°-78°E and to the South of 65°30'S (x 10^6 tonnes)	Seasonal Krill Consumption (x 10^6 tonnes)	Percentage of Yearly Krill Production Consumed
	Min-Max	Median			
1978	50 - 83	62	2.5 - 3.0	0.093	3.4
1982	14 - 23	17.5	2.5 - 2.8	0.026	1.0
1984	41.5 - 69	52	2.5 - 3.0	0.078	2.8
1986	68 - 113.5	85	1.0	0.128	12.8
1987*	-	22	0.3	0.033	11.0

* *P. antarcticum* stock calculated over a very small area.

Table 6: Antarctic krill consumption by coastal-dwelling fishes in the Sodruzhestva Sea (55 to 80°E) from December to April. Fish stock size calculated for a depth range of 100 to 500 m.

Species	Stock Size (tonnes)	Seasonal Diet (body mass)	Percentage of Krill in the Stomach	Krill Consumption (tonnes)
Chaenodraco wilsoni	45305	3.64	64	105543
Trematomus eulepidotus	67946	4.965	53	178797
Pleuragramma antarcticum	89411	1.5	90	120705
T. hansoni	6068	5.25	12	3823
Chionodraco hamatus	19665	2.4	48	22654
C. mayersi	10156	2.4	10	2437
Cryodraco antarcticus	2435	3.3	0.2	16
Lepidonotothen kempi	1930	5.25	1	101
T. centronotus	649	3.0	8.5	166
Dissostichus mawsoni	1128	5.25	3	178
Cygnodraco mawsoni	765	1.5	18	207
Neopagetopsis ionah	6880	3.3	40	9082
Pogonophrine sp.	173	3.0	5	26
Bathyraja sp.	1798	1.5	20	539
T. nicolai	925	3.75	4	139
Notothenia coriiceps	214	5.25	0	0
Other: *P. macropterus, T. bernachii, G. acuticeps, T. scotti, H. velifer, P. borchgrevinki, T. lepidorchinus,* and *M. whitsoni*	267	3.75	0-85 (on average 25)	250
Total	255715	3.12	62.2	444663

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