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PLIOCENE DIATOM ABUNDANCE AS PROXY FOR TEMPERATURE IN WEDDELL SEA: ODP SITE 697

ELENA ROBAKIEWICZ, Oberlin College
Research Advisors: Karla Hubbard and Suzanne O'Connell

ABSTRACT

During the Pliocene, carbon dioxide in the atmosphere was approximately 400 ppm. Today's atmosphere exhibits similar carbon dioxide levels. Analyzing diatom abundance and changes in species diversity in the Weddell Sea during the Pliocene provides insight into temperature and sea-ice cover changes during this important time interval. Diatom abundance and diversity at ODP Site 697 displays distinct species oscillations between 3.26 to 3.03 million years ago. Colder periods include 3.23 mya, 3.08 mya, and begin again around 3.03 mya.

INTRODUCTION

The Pliocene, which spanned 5.33 to 2.58 million years, was a warm interval that preceded glaciation with many analogs to today. The comparison of the Pliocene to the current epoch, the late Holocene/ Anthropocene, is vital to understanding climate's future. Cores 13X and 14X from ODP site 697 at S61°48' and W40°17' in the Jane Basin of the Weddell Sea east of the Antarctic Peninsula penetrates Pliocene sediments.

Diatoms are used as climate indicators because they are often restricted to environments based on temperature, salinity, and water depth. Burckle and Cirilli (1987) determined that diatom abundance can be indicative of the amount of sea-ice cover, with fewer diatoms during times of greater sea-ice cover. Further studies show that there are particular species of modern diatoms that are more abundant at certain temperatures and percentages of sea-ice cover (Armand et al., 2005; Crosta et al., 2005; and Romero et al., 2005; and papers cited therein).

Pudsey (1990) used sediments from Site 697 to determine diatom abundance and connect it with grain size. Pudsey noted variation in diatom abundance from 3.8 to 3.1 million years ago, but was unable to find a correlation between diatom abundance and grain size, which is normally indicative of the amount of ice calving, or increasing temperatures (Pudsey, 1990).

This research also continues to examine questions on changes in temperatures observed by Harwood et al. (personal communication) during the Pliocene. The aim of this study is to examine diatom abundance and diversity during the Pliocene, specifically 3.26 to 3.03 million years ago. The data are expected to reflect ocean temperatures and ice cover in the Weddell Sea.

METHODOLOGIES

Retrieving Sediment from Core

Samples of the cores from Site 697 were taken at the IODP core repository at Texas A&M University. Approximately 10 cc, samples were taken about 50 cm apart (depending on the preservation of the core as often cracks form, making it difficult to take samples).

Preparing Diatom Slides

After the samples were freeze-dried, the Warnock-Scherer method (Warnock and Scherer, 2014) was used to create the slides. This method uses settling tanks to evenly and randomly distribute the sample for diatom slides that will be statistically similar. A known-mass of freeze-dried sediment of about 0.07 grams was reacted with 10% hydrogen peroxide for 12 hours to remove any biomass and to disaggregate clumps. The settling chamber was filled with 2 L of water and a drop of surfactant dispersing agent is added. The sediment was added to the H_2O_2 solution and then swished around before it was poured into the settling chamber which had the coverslips sitting on a table above the chamber's drain spout. The solution was left to settle for 6 hours, at which point it was drained at a rate of a couple drops per second. Once the chamber had drained and dried, the coverslips were covered with a slide using diatom mounting epoxy, adding heat to get rid of any large bubbles (Warner and Scherer, 2014).

Method for Counting Diatom Abundance

Diatoms were counted using a light microscope at 100X. On each slide, the diatoms were counted on random paths, twice horizontal and twice vertical, to ensure a random sampling of diatoms. Diatoms were only counted if over half of the diatom was visible. If less than half of a diatom was visible with another half nearby, they were also counted as one. Twenty slides were counted. No slides were counted more than once (Appendix 1). Ages for the core are taken from the polarity reversal stratigraphic of Hamilton and O'Brien (in prep in Pudsey 1990) using the ages of Gee and Kent (2007).

RESULTS

Diatom abundance varied from 122 on the slide from Core 13X_1 from the intervals 133 to 135 cm from 3.06 million years ago to 1319 on the slide from Core 13X_1 from the intervals 5 to 7 cm from 3.03 million years ago (Appendix 1).

Sea-ice species are typically confined southward of the Polar Front and are observed either within, on, in, or around sea ice (Armand et al., 2005; Tréguer and Jacques, 1992). The sea ice species in this research include *A. actinochilus*, *F. curta*, *F. ritscheri*, *F. sublinearis*, *P. glacialis*, *P. pseudodenticulata*, *S. microtrias*, *T. antarctica* Group, and *Chaetoceros* resting spores (Figure 1 a&b). Armand et al.'s (2005)

Species	Temperature (deg. C)	Other Notes	Sources
Actinocyclus actinochilus (Ehrenberg) Simonsen	0 to 1	Associated with significant ice cover	(Garrison et al., 1983)
Fragilariopsis curta (Van Heurck) Hustedt	-1 to 2.5 Max: .5 to 1	Associated with water column near the edge of sea ice	(Garrison et al., 1982)
Fragilariopsis ritscheri Hustedt	0 to 3	Associated with water column near the edge of sea ice	(Garrison et al., 1982)
Fragilariopsis sublinearis (Van Heurck) Heiden	-1.3 to 2.5	Sea-ice concentrations greater than 70% in February	(Garrison et al., 1982)
Porosira glacialis (Grunow) Jbrgensen	-1.3 to 2 Max: 0 to .5		(Armand et al., 2005)
Porosira pseudodenticulata (Hustedt) Jouse	-1.3 to 2	Uncertain whether species prefers water column or sea ice	(Armand et al., 2005)
Stellarima microtrias (Ehrenberg) Hasle et Sims	-1.3 to 3.5 Max: -.5 to .5	Associated with newly forming sea ice	(Armand et al., 2005)
Thalassiosira antarctica Group	0 to .5		(Armand et al., 2005)
Chaetoceros resting spores	-.5 to 1.5	Relation to ice cover is poorly understood	(Armand et al., 2005)
Fragilariopsis kerguelensis (O'Meara) Hustedt	1 to 8 Min: < 0; >20	No preference between ice covered or ice-free	(Crosta et al., 2005)
Thalassiosira lentiginosa (Janisch) Fryxell	1 to 8 Min: about 18	Pelagic but can exist in ice-covered conditions	(Crosta et al., 2005)
Thalassiosira oliverana (O'Meara) Makarova et Nikolaev	2 to 4	Associated with open waters	(Crosta et al., 2005)
Shionodiscus oestrupii (Ostenfeld) A.J.Alverson, S.H.Kang & E.C.Theriot	>11		(Romero et al., 2005)

Table 1. Temperature proxy species found in this study, their preferred living temperature, and notes on living habits. Max gives the temperature range at which the species is most abundant.

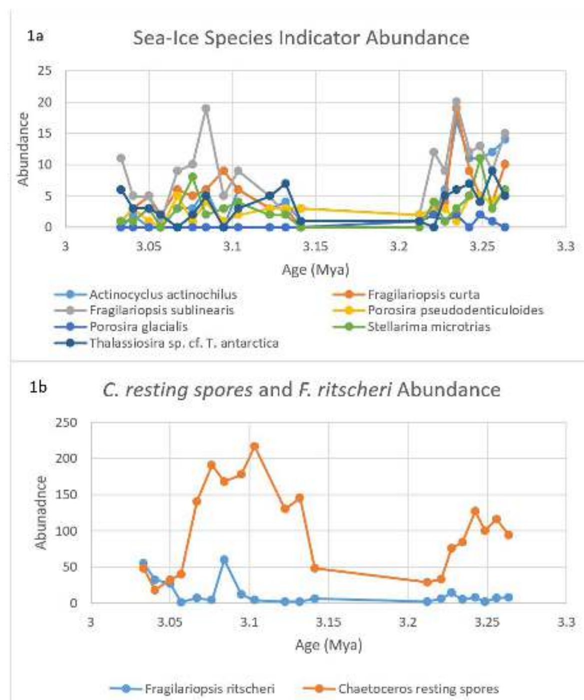

Figure 1 a&b. (1a) displays the abundance of sea-ice species indicators as identified by Armand et al. (2005) without Chaetoceros resting spores. (1b) displays the abundance of Chaetoceros resting spores and Fragilariopsis Ritscheri separated from the other species, as they are an order of magnitude greater in abundance than the other sea-ice diatoms.

T. antarctica Group consists of *T. antarctica* and *T. scotia*. In this core, only *Thalassiosira antarctica* was found. There are 75 different species of *Chaetoceros* that form resting spores. Although it is presumed that species produce the higher-silica resting spore shells when the water temperature is cooler, their relation to ice cover is poorly understood (Armand et al. 2005).

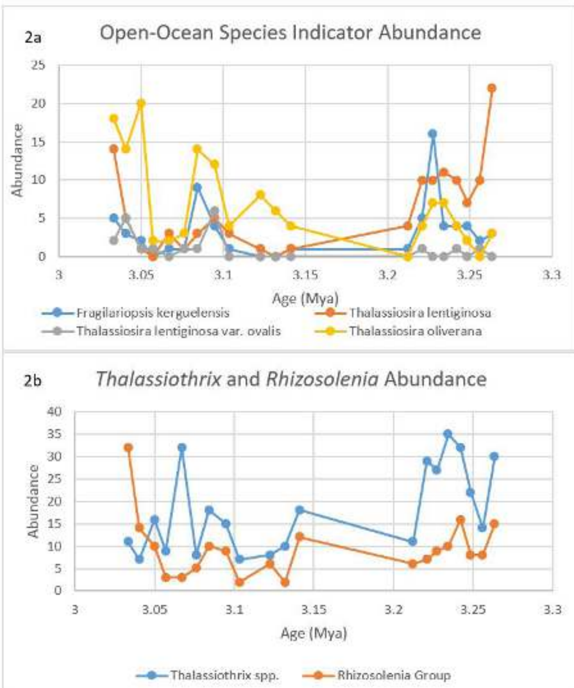

Figure 2 a&b. 2a) displays the abundance of open-ocean species indicators as identified by Crosta et al. (2005). (2b) shows the abundance of Thalassiothrix spp. and Rhizosolenia group. These two groups were kept separated from the rest of the data because their scale of abundance is larger and because their utility in being indicator fossils is less reliable.

The open-ocean species are representative of areas of lower sea-ice cover and warmer temperatures (Tre´guer and Jacques, 1992). Open-ocean species include *F. kerguelensis*, *T. lentiginosa*, and *T. oliverana* which are all present in the core (Figure 2 a&b). *T. lentiginosa var. ovalis* is plotted separately as it is thought to be a warm-climate variety of *T. lentiginosa*. Other genera considered open-ocean genera not included in the table, include *Rhizosolenia* Group and *Thalassiothrix* spp. The *Rhizosolenia* Group is not included in the averages because data on the species names has been inconsistent. They divide this group into the "straight group" and the "rounded group" but recent name changes have made this group difficult to work with (Crosta et al., 2005). *Thalassiothrix* spp. is also not used in the averages because its abundance is so much greater than the rest and makes the visuals difficult to see. In addition, its maximum abundance is between 1 and 3 degrees C, but has still been found to be abundant between 11 and 20 degrees C, a range too large to be used as a climate proxy (Crosta et al., 2005).

S. oestrupii is the only species labeled as a tropical/subtropical indicator species by Romero et al. (2005) apparent in abundance within the slides.

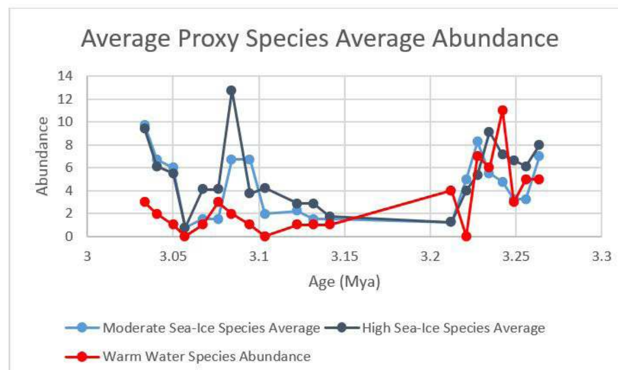

Figure 3. Averages of sea-ice species and open-ocean species. The diagrams also displays the abundance of Shionodiscus oestrupii, a warm water species. Figure 2 a&b. (2a) displays the abundance of open-ocean species indicators as identified by Crosta et al. (2005). (2b) shows the abundance of Thalassiothrix spp. and Rhizosolenia group. These two groups were kept separated from the rest of the data because their scale of abundance is larger and because their utility in being indicator fossils is less reliable.

Based on Figure 3, it appears that there are two distinctly colder periods in this part of the Pliocene, one at 3.08 mya and 3.23 mya. It also appears that the climate is moderate 3.23 mya and 3.09 mya. There appears to have been the warmest temperatures at 3.24 mya and 3.21 mya. Other possible climate estimates based on this figure include cooling from 3.14 to 3.10 mya and a cooling period from 3.05 to 3.03 mya.

DISCUSSION

Diatom abundance and differences in distribution can be used to reconstruct ancient oceanic temperatures and sea ice cover. Life habits of modern species can be applied to the past in order to give us better understanding of previous sea temperatures. By utilizing the averages of certain indicator species, we can reconstruct the ocean temperatures during the Pliocene.

Figure 3 displays prominent trends between sea-ice cover and warmer waters. Species abundance suggests that 3.26 mya temperatures were cool. Twenty thousand years later, at 3.24 mya temperatures warmed slightly but began to cool again after that. Approximately eight thousand years later (at 3.23 mya) data strongly suggests a high sea-ice cover period. From this point, it appears that the ocean warmed slightly, with a peak warmth at 3.21 mya. But include a definite cool period at 3.23 mya. After 3.14 mya, the oceans cooled, with a strong point of high sea-ice cover at 3.08 mya and a strong cool period 3.09 mya. From this point, it is likely that ocean temperatures cooled as evidenced through the increase in high sea-ice abundance and moderate sea-ice abundance from 3.06 mya to 3.03 mya.

When comparing the data of temperature proxy diatoms and the data of total abundance of diatoms, it appears that the total abundance is actually a measure of the coolness of the ocean as opposed to the warmness (Figure 1). These data question the assumptions posed by Burckle and Cirilli (1987) who stated that the presence of 75% sea-ice cover is reflected in reduced diatom accumulation. This poses the question, can diatom abundance be used as proxies for temperature, especially in the Southern Ocean? Instead these data suggests that variation in species abundance are likely a better indicator of temperature.

Difficulties in this data set include pore core preservation and lack of recovery. For example, data from 3.21 mya to 3.14 mya (134.47 to 138.28 meters below sea floor) is missing due to no recovery. Because of this, we cannot compile a complete climatic history of the Southern Ocean. This entire study spans approximately, less than 300kyr. A longer record must be utilized if we want a complete picture of temperatures of the Southern Ocean in the Pliocene. Also, there are errors that can occur during the identifying process such as misidentification and miscounting. Of the temperature proxy diatoms, *S. oestruppi*, the tropical/subtropical proxy, poses difficulties. At the time of the Romero et al. 2005 paper, *S. oestruppi* was still part of the *Thalassiosira* genus. Since then, *S. oestruppi* has changed genera and another, very similar, species, *Shionodiscus tetraoestruppi*, has been identified. This difference in identification is slight, with only a difference in the shape of the shell's areolae, which means that these organisms could have been misidentified or that Romero et al.'s (2005) data could be combining, confusing, or misusing *S. tetraoestruppi* as their claimed *T. oestruppi*, altering the results. Thus, although *S. oestruppi* is labeled in this study as a tropical/subtropical climate indicator, it's relevance to climate may not be known.

CONCLUSION

The data collected are from Cores 697B_13X and 14X from the Weddell Sea (approximately 3.27 to 3.03 mya). Data show that diatom abundance in this area is indicative of a cool climate. Temperature proxy species are useful in identifying cool and cooler periods which seems to have cycled throughout the late Pliocene. The data supports a cooler ocean with higher sea-ice cover 3.23 million years ago followed by a slight warming trend until diatom species indicate cooler waters beginning at 3.08 million years ago. Another slight warming period gradually leads into a cooling period 3.03 million years ago which appears to trend into a cooler environment past the available data. This work is important as it provides detailed climate variation in the Southern Ocean throughout the late Pliocene. Further research should be done to expand our results farther back in the Pliocene using additional cores from Site 697.

APPENDICES

SAMPLE INTERVAL	Meters Below Sea Floor	Age (mya)	ABUNDANCE	Actinocyclus actinochilus	Actinocyclus dimorphus	Actinocyclus ingens	Actinocyclus karsteni	Actinocyclus open center	Actinocyclus spp.	Azpetia tabularis	Chaetoceros resting spores	Centric Diatoms too tilted or domed	Corethron spine
978_13X_1W_5-7	128.66	3.033	VA		5		6		7	1	48		
978_13X_1W_46-48	129.05	3.041	F	2	3	1	3		1	0	18		
978_13X_1W_95-97	129.56	3.050	F		5		2	1		0	32	1	
978_13X_1W_133-135	129.94	3.057	R							0	40		
978_13X_2W_37-39	130.48	3.067	F	3			3		3	0	141		
978_13X_2W_87-89	130.98	3.076	F	3		1	7		3	0	191		
978_13X_2W_130-132	131.41	3.084	A	6		3	12	1	3	2	168	2	
978_13X_3W_37-39	131.98	3.095	C			4	9		2	1	178	6	
978_13X_3W_91-93	132.445	3.103	C	6		3	8		2	0	217		
978_13X_4W_36-38	133.47	3.122	F	3		2	4			0	130		
978_13X_4W_86-88	133.97	3.132	F	4			10			0	146		
978_13X_4W_136-138	134.47	3.141	R	1	1					0	48		
978_14X_1W_7-9	138.28	3.212	R	1		2	4	1	2	1	29	1	
978_14X_1W_57-59	138.78	3.221	F	2	1	4	4		6	0	33	3	3
978_14X_1W_110-112	139.31	3.228	C	6	3	4	10	1	4	0	76	7	4
978_14X_2W_15-17	139.86	3.234	A	17	3	1	6		2	0	84	4	10
978_14X_2W_79-81	140.5	3.242	A	11	4	4			2	0	127		16
978_14X_2W_130-132	141.01	3.249	C	11	3	6	3	6	3	0	100	3	38
978_14X_3W_40-42	141.61	3.256	C	12	11		2	3	7	0	116	5	20
978_14X_3W_102-104	142.23	3.264	A	14	3	3	6	6	2	0	94	6	35

SAMPLE INTERVAL	Cocconeis	Coscinodiscus spp.	Dactyliosolen antarcticus	Dicladia capreola	Eucampia antarctica	Fragilariopsis aurica	Fragilariopsis arcula	Fragilariopsis barroni	Fragilariopsis curta	Fragilariopsis kerguelensis	Fragillariopsis interfrigidaria	Fragilariopsis obliquecostata	Fragillariopsis praecurta	Fragillariopsis praeinterfrigidaria	Fragilariopsis rhombica	Fragilariopsis ritscheri	Fragilariopsis sublinearis	Fragilariopsis weaverii	Fragilariopsis spp.	Pluerosignma spp	Porosira pseudodenticuloides	Porosira glacialis	Rhizosolenia harwoodii	Rhizosolenia hebetata group
978_13X_1W_5-7	2	1		1	8	25		4	1	5			8	13	1	55	11		15		1	0	22	7
978_13X_1W_46-48		1		0	8	18	3	6	3	3	1		6	9		32	5		21		3	0	11	1
978_13X_1W_95-97				0	10	7	1	2	5	2		1	5	3	1	27	5		9		1	0	6	1
978_13X_1W_133-135				2	3		1	2	2	0			6	4		1	1	1			0	0	2	
978_13X_2W_37-39				1	7			3	6	1			19	6	1	7	9		1	1	5	0	2	1
978_13X_2W_87-89				4	3	1		3	5	1	1		16	6		4	10		1		1	0	4	1
978_13X_2W_130-132	1		3	3	10	9	6	56	6	9			33	29	1	60	19			1	4	0	5	5
978_13X_3W_37-39			7	1	10			10	9	4	1		20	18		12	5				1	0	3	4
978_13X_3W_91-93			4	0	8		1	5	6	1	2		25	13		4	9		1	1	2	0	2	
978_13X_4W_36-38				1	6			3	3	0			9	10		2	5				3	0	5	1
978_13X_4W_86-88		1	1	0	7	2	1	4	3	0	1		9	11		2	2	2			3	0	1	1
978_13X_4W_136-138				2	4			3	0	1			3	4		6	3		2		3	0	11	1
978_14X_1W_7-9			1	1	7		1	3	1	1				3		2	2				2	1	5	1
978_14X_1W_57-59			1	0	26	1		22	3	5			1	12		6	12	1			3	2	2	5
978_14X_1W_110-112			4	4	63	3		48	4	16	2		1	41		14	9	1	1		3	1	4	5
978_14X_2W_15-17	2	2	1	10	99	4		21	19	4			19	59		5	20	1	4	2	1	2	4	4
978_14X_2W_79-81	1	2	2	10	76	3		17	9	4	2		1	98		8	12				5	0	7	6
978_14X_2W_130-132			7	11	92	1		11	5	4			5	24		2	13		3		5	2	4	1
978_14X_3W_40-42	1	2	2	15	57	6		4	4	2	3		4	33		7	9		3		4	1	3	
978_14X_3W_102-104	2	2	2	16	58	1		21	10	3				53		8	15		4	1	6	0	11	2

SAMPLE INTERVAL	Rhizosolenia styliformis	Rouxia antarctica	Rouxia diploneidies	Rouxia naviculoides	Rouxia isopolica	Rouxia spp.	Shionodiscus oestrupi	Shionodiscus tetraoestrupi var reimer	Stellarima microtrias	Stellarima stellaris	Stephanopyxis spp.	Synedropsis lata (mummy)	Synedrpsis sp. without capitate ends	Thalassiosira sp. cf. T. antarctica	Thalassiosira complicata	Thalassiosira elliptopora
978_13X_1W_5-7	3	20	878	3	1		3	4	1		11	1	2	6	1	1
978_13X_1W_46-48	2	28	8	7	5	4	2		1		6	6	1	3		1
978_13X_1W_95-97	3	23	1	8	5	2	1	2	3		10	5	4	3	1	
978_13X_1W_133-135	1	5	2	5	1	1	0	3	0		8	4	1	2		
978_13X_2W_37-39		16	1	3		13	1	1	3		7	5	2	0		1
978_13X_2W_87-89		12	1	3	2	1	3	5	8		4	5	2	2	2	2
978_13X_2W_130-132		47	4	17	11		2	8	2	1	3	9	5	5	2	2
978_13X_3W_37-39	2	45	6	8	15	1	1		3		2	12	4	0		2
978_13X_3W_91-93		6	3	1	4	3	0	2	4		13	8	5	3		1
978_13X_4W_36-38		12	2	4		3	1	3	2		2	11	2	5		
978_13X_4W_86-88		13	2	6	2	2	1	2	2			9	5	7		
978_13X_4W_136-138		1		1	1	5	1	4	0			5	1	1		
978_14X_1W_7-9		1				1	4	1	0		2	2	2	1	1	1
978_14X_1W_57-59		8	1	10	1	7	0	3	4		4		1	0		1
978_14X_1W_110-112		26	7	22	10	9	7	13	1	1	9	2	1	5		2
978_14X_2W_15-17	2	51	10	43	23	12	6	25	3		15	11	3	6	3	4
978_14X_2W_79-81	3	34	5	32	5	8	11	29	5	1	14	14		7	1	1
978_14X_2W_130-132	3	33	2	7	6	11	3	14	11		19	8		4	2	2
978_14X_3W_40-42	5	68	4	35	17	15	5	18	3	1	13	21	1	9	5	3
978_14X_3W_102-104	2	74	9	31	25	7	5	21	6	1	13	20	1	5	3	5

SAMPLE INTERVAL	T. fasciculata group	Thalassiosira fasciculata	Thalassiosira gravida	Thalassiosira inura	Thalassiosira kolbei	Thalassiosira lentiginosa	Thalassiosira lentiginosa var. ovalis	Thalassiosira oliverana	T. sparsa group	Thalassiosira species 1: thin, small, te	Thalassiosira striata	Thalassiosira torokina	T. tumida group	Thalassiosira vulnifica	Thalassiosira webbi	Thalassiosira spp.	Thalassiothrix spp.	silicoflag - Stephanocha speculum
978_13X_1W_5-7	1	8		17	1	14	2	18			28	5	1	10		6	11	15
978_13X_1W_46-48	2	13	3	12	1	5	5	14	1		10	3	3	3	3	9	7	1
978_13X_1W_95-97	1	5	1	10	2	1	1	20	2		4	5	2	4	1	2	16	3
978_13X_1W_133-135		5				0	1	2			2		2	2	1		9	
978_13X_2W_37-39	2	6	1	8		3	0	2		2	13	5		16	2	3	32	3
978_13X_2W_87-89		2	3	3		1	1	3	1		13	5	6	4		2	8	7
978_13X_2W_130-132		12	3	21	1	3	1	14			33	3		22		19	18	16
978_13X_3W_37-39		11	5	11	1	5	6	12	4		47	3	2	16	2	11	15	20
978_13X_3W_91-93		2	3	9	1	3	0	4			12	2	5	7		11	7	4
978_13X_4W_36-38		3	2	5		1	0	8		1	10	4	2	7		5	8	13
978_13X_4W_86-88		6	8	9		0	0	6		3	8	8		4	2	5	10	2
978_13X_4W_136-138	1	2	4	14		1	0	4		2	7	3	1	7	1	3	18	
978_14X_1W_7-9		4	1	5	2	4	0	0			14	3	2	3	1	3	11	2
978_14X_1W_57-59	2	16	3	8	1	10	1	4			27	4	14	9	3	16	29	29
978_14X_1W_110-112	1	16	9	7	6	10	0	7		9	10	4	9	6		15	27	46
978_14X_2W_15-17	3	13	6		4	11	0	7		37	19	4	2	19	4	5	35	35
978_14X_2W_79-81	1	23	1	8	7	10	1	4		84	15	8	13	8	5	20	32	87
978_14X_2W_130-132	6	19	1	4	4	7	0	2		32	22	8	2	14	2	7	22	39
978_14X_3W_40-42	3	3	1	3	5	10	1	0		37	13	5	4	4	7	18	14	29
978_14X_3W_102-104	10	18		5	4	22	0	3		97	29	3	7	13	6	1	30	22

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