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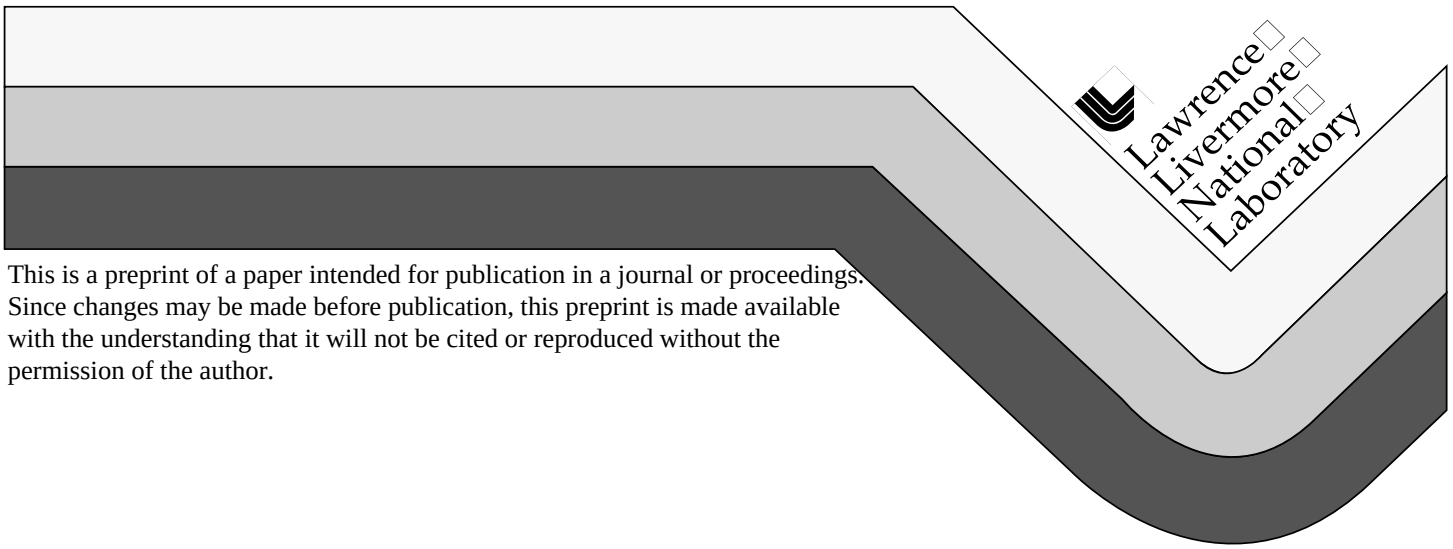

Spatial variations of particle scavenging rates within the central and northern Adriatic Sea: use of U-Th disequilibria

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Abstract

Dissolved and particlulate Thorium-234 (^{234}Th) were measured in near surface waters from the Central and Northern Adriatic Sea in order to gain an insight into the intensity and variability of active scavenging and particle removal processes. Dissolved ^{234}Th to Uranium-238 (^{238}U) activity ratios vary from 0.21 to 0.75 and clearly imply that ^{234}Th is being actively scavenged from sea water on a timescale of <3 months. The scavenging rate of dissolved ^{234}Th with respect to scavenging onto particles appears to correlate with primary productivity measurements. Scavenging and rapid removal of particulate ^{234}Th from the water column is best explained by a mechanism of zooplankton grazing and fecal pellet production. At one sight in the Jabuka Pit, particulate ^{234}Th residence times below the pycnocline are long (30-40 days) suggesting that particles are being more readily recycled at these depths. By comparison, in a seawater profile collected near the Po outflow region, ^{234}Th is depleted with respect to ^{238}U through the entire water column. We conclude from this assessment that particles in waters near the Po River outflow will be more efficiently transported to bottom sediments compared with those in deeper waters over the Jabuka Pit.

Key words: ^{234}Th, Adriatic Sea, scavenging, residence times

1. Introduction

The half-lives and biogeochemistry of ^{234}Th ($t_{1/2}$ = 24.1 days), Polonium-210 (^{210}Po) ($t_{1/2}$ = 138.4 days) and Lead-210 (^{210}Pb) ($t_{1/2}$ = 22.3 years) are ideal for studying particle dynamics in the upper water column (Aller and Cochran, 1976; Bacon *et al*., 1976; Coale and Bruland, 1985). Models based on ^{234}Th: ^{238}U disequilibria have been successfully used to estimate scavenging

rates of dissolved Th onto particles, particle residence times and the ^{234}Th flux or removal on sinking particles (Coale and Bruland, 1987). Moreover, it has been observed that the residence time of dissolved ^{234}Th with respect to removal on biogenic particles is inversely proportional to primary productivity and may be used to predict export from or 'new' production in the euphotic zone (Coale and Bruland, 1985; Coale and Bruland, 1987). Model-derived ^{234}Th fluxes can also be used to help validate sediment trap collections in the upper water column (Buesseler, 1991). The aim of the present study was to gain an insight into the intensity and variability of active scavenging and particle removal processes in the central and northern Adriatic Sea. This semi-enclosed sea is strongly influenced by fresh water runoff from rivers carrying large quantities of dissolved nutrients and suspended particles. These inputs of nutrients and suspended particles are expected to give rise to large biological and biogeochemical gradients across the continental shelf and offer a range of environments for studying particle scavenging and removal processes. As such, we have examined the relationships between ^{234}Th scavenging rates and residence times of dissolved and particulate phases as a function of other physical and biological parameters [primary productivity, POC, chlorophyll, C/N and total suspended matter (TSM)]. Particular reference is made to the two contrasting environments of the Adriatic Sea—a eutrophic zone near the Po River outflow and in the largely oligotrophic waters of the Jabuka Pit.

2. Methods

Samples for dissolved and particulate ^{234}Th were collected from eight stations in the northern and central Adriatic Sea during the ELNA6 in July 1994 (Fig. 1). More detailed water column profiles were collected from two sites: at St. 34 & 36 close to the Po outflow region and at St. 87 in the Jabuka Pit. At each of the five other stations water samples were collected from a single depth below the mixed layer close to the chlorophyll maximum. Nishkin bottles attached to a CTD rosette sampler were used to collect samples of seawater for chemical and biological parameters, i.e., TSM, chlorophyll, particulate organic carbon and nitrogen, and primary productivity.

Dissolved and particulate radionuclides were collected using large volume *in-situ* particle samplers (Challenger Oceanics, UK). The water passes sequentially through a 0.45 μm Asypor filter membrane fitted to the head of the pump and two MnO_2-impregnated polypropylene cartridges. Immediately after recovering the pumps, the MnO_2-impregnated cartridges containing the dissolved phases were rinsed with deionized water to remove excess sea salt and placed in plastic bags. The Asypor membrane filters containing the particulate matter were stored in a freezer. Cartridge scavenging efficiency was determined from the relative radionuclide activities found on the first and second cartridges as defined by the equation, 1 -

B/A, where A is the first in-line cartridge and B is the second (after Buesseler *et al*., 1992). A full description of the field and laboratory techniques will be described elsewhere (Hamilton & Fowler, in prep.).

2.1 Radionuclides

^{234}Th was stripped from the MnO_2-impregnated cartridges using a mixture of 10% HNO_3-H_2O_2. The Asypor membrane filters were digested in concentrated nitric acid with addition of a few drops of HF to dissolve any siliceous material. A known amount of ^{230}Th tracer was added to each sample as yield determinant. The filter digest was diluted to a volume of 50ml and an aliquot retained for ICP-MS analyses.

Thorium isotopes were separated by extraction into 30% Aliquat-336 in xylene from 2M $HN0_3$, and then back extracted into 10M HCl extraction. The thorium fraction was then evaporated to dryness with addition of HNO_3, and electrodeposited onto stainless steel discs using a H_2SO_4-Na_2SO_4 electrolyte solution. The ^{234}Th activity on the discs was measured using a gas-proportional beta counter (Risø, Denmark). The sample discs were also counted by alpha-spectrometry in order to determine the chemical recovery of ^{230}Th. The total propagated counting errors ranged between 3 and 5%, and 3 and 8% for soluble and particulate ^{284}Th, respectively.

2.2 Measurements of Primary Productivity, POC, TSM and Chlorophyll.

Primary productivity was measured using $^{14}CO_2$ incorporation in a temperature controlled, artificial light incubator under seven different photon intensities (0-600 mmol m^{-2} s^{-1}) for 2 hours at ambient mean water column temperature. Samples removed from the incubator were size-fractionated by sequential filtration through 8, 3 and 0.2 mm cellulose nitrate filters. The filters were dried over acid and stored at -5°C. A Tri-Carb 1600TR liquid scintillation analyzer (Packard Instruments) was used for the measurements. The quantity of ^{14}C incorporated in dark control bottles was subtracted from the sample bottles and productivity versus irradiance curves for the individual depths were constructed. No correction was made for isotope discrimination or respiratory loss. Details of the model from which all primary productivity estimates are based will be given in this volume (see Heilmann & Richardson).

Between 2 and 6 litres of seawater were filtered onto preweighed, precombusted glassfiber filters (GF/F) for analysis of POC, PON and TSM. Sea salt was removed by rinsing the filter with a few ml of distilled water. A separate aliquot of seawater was filtered for measurement of Chlorophyll *a* (Chl. *a*). The filters used for POC and TSM were oven dried at 60°C to constant weight. Particulate C and N were measured by combustion in a HERAEUS CHN-Elemental

Analyser. POC samples were pretreated with 1M phosphoric acid to remove carbonate carbon prior to analysis.

2.3 Modeling of U:Th Disequilibria

The residence times of dissolved and particulate ^{234}Th in the Adriatic Sea were calculated using the scavenging model of Coale and Bruland (1985) and Aller and Cochran (1976). ^{234}Th ($t_{1/2}$ = 24.1 days) is produced throughout the water column at a rate proportional to the decay of its conservative parent, ^{238}U. The supply of dissolved ^{234}Th ($A_U\lambda_{Th}$) using a steady state assumption will be balanced by decay ($A^d_{Th}\lambda_{Th}$) and scavenging onto particles (J_{Th}). A mass balance equation may be expressed as:

$$A_U\lambda_{Th} = A^d_{Th}\lambda_{Th} + J_{Th} \quad (1)$$

Assuming that scavenging of dissolved ^{234}Th onto particles follows first order kinectics, a scavenging rate constant (K_d) can be defined, where

$$K_d = J_{Th}/A^d_{Th} \quad (2)$$

that is the reciprocal of the residence time (τ_d) for dissolved ^{234}Th. Substituting in equation 1, the scavenging rate coefficients (K_d, d^{-1}) can be calculated from measurements of A^d_{Th} and A_U.

$$K_d = (A_U - A^d_{Th})\lambda_{Th}/A^d_{Th} \quad (3)$$

Similarly the particulate ^{234}Th supply (J_{Th}) (see equation 1) is balanced by losses due to radioactive decay ($A^p_{Th}\lambda_{Th}$) and removal by the particle flux (P_{Th}), where

$$J_{Th} = A^p_{Th}\lambda_{Th} + P_{Th} \quad (4)$$

and the mean residence time of particulate ^{234}Th is given by:-

$$\tau_p = A^p_{Th}/P_{Th} \quad (5)$$

By integrating through the water column, measurements of the A_U, A^d_{Th} and A^p_{Th} allow estimates of J_{Th} and P_{Th} to be calculated (Bq m^{-2} d^{-1}). Uranium is a conservative element where the ^{238}U concentration can be expressed as a function of the sea water salinity, i.e., A_U = 1.18 mBq x

salinity. For data reported in this study, particulate and total sea water ^{238}U concentrations (and particulate ^{232}Th) have been measured directly by isotope dilution ICP-MS.

3. Results and Discussion

Data on each of the eight stations sampled during the 1994 summer cruise (ELNA6, 27 July-2 August) are summarized in Table 1. Water column profiles were collected from Station 34/36 (Po outflow region) and Station 87 in the Jabuka Pit (Fig. 1). Integrated chlorophyll and primary productivity measurements are taken from Heilmann & Richardson (this volume). Compared to the ELNA2 and ELNA3 summer cruise there was a greater presence of freshwater during ELNA6. Depressed surface salinities observed over the entire observational area may have important consequences for studying particle scavenging processes because of the presence of lithogenic particles in the water column. Both lithogenic and biogenic particles may be responsible for scavenging of dissolved ^{234}Th as well as other particle reactive radionuclides in seawater. Our study is also limited to one observational period (within the summer stratified season) and, therefore, may not be representative of seasonal conditions.

3.1 ^{234}Th Scavenging and Residence Times

The concentrations of dissolved, particulate and total ^{234}Th, as well as particulate ^{232}Th, at each of the stations are presented in Table 2. Within the precision of our ICP-MS analyses (±3-8 %), the ^{238}U concentration of unfiltered seawater was consistent with values normalized to 35 ppt salinity for the open-ocean. We have therefore used the ^{238}U-salinity relationship for open ocean waters to estimate the total supported ^{234}Th (A_U) in the water column as described by Ku *et al.* (1977) in all calculations.

The A^d_{Th}:A_U activity ratios vary from 0.21 to 0.75 and clearly imply that ^{234}Th is being actively scavenged from sea water on a timescale of <3 months. The concentration of dissolved ^{232}Th in seawater is extremely low and much of the ^{232}Th delivered by rivers will be in particulate form. We can therefore use particulate ^{232}Th as a measure of the relative contribution of inorganic (lithogenic) to the total suspended particulate load in the water column. In general, particulate ^{232}Th concentrations do appear to decrease away from the Po outflow region (St. 34/36) and other near-shore stations (St. 74 & 71). The lowest values occur in surface waters of the Jabuka Pit in the central Adriatic Sea (0.002-0.004 ng l^{-1}) (St. 87) (see Table 2 and Fig. 1). High concentrations of particulate ^{232}Th (0.23-0.37 ng L^{-1}) were found at St. 74 and at a depth of 80 m in the Jabuka Pit (St. 87). We estimate that the total lithogenic contribution to the suspended particulate load for these two water samples to be about 8 % and 13 %, respectively. St. 74 was

located in shallow water close to the Italian coast (Fig. 1) where we would expect to see high concentrations of inorganic particles in the water column from resuspension of sediments and inputs from land. The relatively high concentration of particulate ^{232}Th in the 80m sample from St. 87 is more difficult to explain. The most probable explanation is contamination although sample filters were handled with great care in order to avoid such problems. Another possible source of particulate Th is lateral transport of resuspended sediment from the upper slope of the Pit. However, there appears to be no direct evidence to support this claim.

The residence time of dissolved ^{234}Th with respect to scavenging onto particles varies between 9 and 79 days for samples taken above the pycnocline and between 16 and 109 days below (Table 3). These values compare with 1.4 d for Long Island Sound (Aller & Cochran, 1976), 0.3-0.9 days for the Yangtze continental shelf (McKee *et al.*, 1984), 0.5-7.7 days for the Eastern Irish Sea (Kershaw and Young, 1988) and between 6-101 days for the open ocean (Coale and Bruland, 1985; Shimmield *et al.*, 1995). Hence, the residence times appear to fall in an intermediate range between typical values observed in coastal areas and those in the open ocean. By comparison, the residence times of particulate ^{234}Th (τ_p) are all <10 days except for two samples taken below the pycnocline from St. 87 in the Jabuka Pit (Table 3.). A short residence time for particulate ^{234}Th implies that Th bearing particles are being rapidly transported. Zooplankton grazing and fecal pellet production appears to be an important factor contributing to the mass-flux of carbon and other biogenic elements in the Adriatic Sea (Miquel *et al.*, this volume). Scavenging and rapid removal of particulate ^{234}Th from the water column can also be explained by a similar mechanism.

A more detailed analysis of the depth distribution of dissolved and particulate ^{234}Th at St. 34/36 and St. 87 was attempted (Fig. 2). Both water column profiles are depleted in ^{234}Th with respect to ^{238}U. At St. 34/36, near the Po outflow region, the disequilibria extends to the near bottom and indicates that particulate ^{234}Th is being removed to the sediments. This is apparently not the case at St. 87 in the Jabuka Pit where dissolved and particulate ^{234}Th are rapidly stripped from the upper 60 m but then appear to approach an equilibium value at a depth of 80 m (see Table 3 and Fig. 2). We can conclude that particles at St. 87 are being more efficiently recycled within the water column compared with St. 34/36. This can be variously attributed to the depth of the water column, the flux of particles reaching the underlying sediments, and greater potential for resuspension of sediments and scavenging of ^{234}Th by lithogenic particles in shallower waters of the Po outflow region.

3.2 POC, TSM, Chlorophyll and Primary Productivity Interrelations

Previous studies on ^{234}Th scavenging have reported a clear correlation between the residence time of dissolved ^{234}Th and the number of particles in suspension (McKee *et al*., 1984; Kershaw and Young, 1988). The two main factors affecting this relationship are (1) the probability that ^{234}Th comes into contact with a particle (which will be directly proportional to concentration of particles), and (2) the nature and reactivity of the available particles. There appears to be no clear correlation between the ^{234}Th residence times and Total Suspended Material (TSM) in our study in the Adriatic Sea (ELNA Progress Report, 1995). The variability in residence times must therefore be controlled largely by variations in particle reactivity and/or active biological uptake. Within our limited data set, the highest scavenging rate coefficients (max. 0.11 d^{-1}) do occur with the highest measured Particulate Organic Carbon (POC) concentration (St. 74). Similarly, the lowest scavenging rate (0.009 d^{-1}) correspond with the lowest measured POC concentration (80 m - St. 87; Table 2 & 3). This implies that biological processes may dominate the ^{234}Th scavenging and removal processes despite the obvious presence of inorganic particles.

Numerous studies have shown that ^{234}Th can be used to quantify particle scavenging and export from the euphotic zone (Coale and Bruland, 1985, 1987; Buesseler *et al*., 1992). We have therefore attempted to investigate the coupling between primary productivity and ^{234}Th scavenging. The scavenging rate of dissolved ^{234}Th with respect to particles (K_d) has been plotted against primary productivity for different phytoplankton cell size ranges in Fig. 3. Data points have been divided into stations taken above the pycnocline (open circles) and those below (filled circles). The depth of the lower pycnocline corresponds with the 1-5% level of photosynthetic active irradiance, and for the purposes of our study we treat this depth as the boundary between euphotic and aphotic zones.

Scavenging rates appear to correlate best with primary productivity occurring in the euphotic rather than the aphotic zone below the pycnocline (Fig. 3a). It is also informative to examine the scavenging rates as a function of phytoplankton cell size (Figs. 3b-d). Scavenging rates versus primary productivity show significant correlations both in terms of first and second order regressions. In general, better correlations can be found by comparing the larger cell sizes with scavenging rates (>8 µm, r^2 = 0.73 for a first order regression on all samples taken above the pycnocline) (Fig. 3d). Heilmann & Richardson (this volume) have suggested that the size structure of the planktonic food web can provide preliminary information about the export capacity from primary productivity. Large-sized phytoplankton are expected to dominate where the food web is maintained by inputs of ‘new’ nutrients whereas in strongly stratified, oligotrophic environments, phytoplankton production will primarily occur in ‘regenerated’ production with a dominance of small-sized phytoplankton. This general hypothesis appears to

be consistent with the use of ^{234}Th as a tool to evaluate 'new' production (Eppley, 1989). Moreover, large diatom cells containing SiO_2 frustules should act as better scavengers of dissolved Th (as well as other particle reactive radionuclides) than small flagellate types which lack hard integument (e.g., see Fisher *et al*., 1983).

In a study on the distribution, activity and cell size structure of phytoplankton in the Adriatic Sea, Heilmann and Richardson (this volume) have suggested that the planktonic community in the northern Adriatic holds a greater potential for carbon export because of the dominance of larger-sized phytoplankton compared to the offshore oligotrophic region within the Jabuka Pit. However, we observed a significant depletion of ^{234}Th in the upper water column of the Jabuka Pit station as well as in the Northern Adriatic (Fig. 2). We believe that the most important process leading to carbon export is zooplankton grazing and fecal pellet production. This process will not necessarily be limited to the larger-sized cells. The presence of ellipsoidal and large cylindrical fecal pellets in trap samples indicated the occurrence of active mesoplankton and euphausiid populations above the traps. Most of the fecal pellets observed in the trap samples were produced by copepods (Miquel and Fowler, unpubl. results). Copepods are able to filter particles as small as 2–3 μm (Raymont, 1983) and could contribute significantly to the removal of Th by repackaging and export as fecal material. Euphausiids (*Euphausia* sp., *Meganyctiphanes norvegica*) feed largely on particles >10 μm and, in this case, grazing will only affect the large cell fraction of phytoplankton. Small-sized phytoplankton such as the flagellates will also be grazed forming micropellets that will be more readily recycled in a microbial loop. If this is true, the temporal and spatial variation in carbon export will depend as much on the dynamics of grazing zooplankton as on the phytoplankton community structure. In relation to this study on ^{234}Th scavenging in the Adriatic Sea, the presence of a greater abundance of small-size cells in the Jabuka Pit area is consistent with the hypothesis that biogenic material in these waters will be more efficiently recycled.

3.3 ^{234}Th-Derived Carbon Fluxes

The irreversible scavenging model adopted from Coale and Bruland (1985) assumes no diffusive or advective transport under steady state conditions. Ideally, we need a time-series of measurements to test these assumptions but this could not be done within the context of the ELNA sampling programme. We do, however, suspect that horizontal advection may be an important source of both dissolved and particulate ^{234}Th especially in the northern Adriatic near the Po River outflow.

The ^{234}Th data has been pooled for Stations 34 and 36 in order to examine the depth distribution of dissolved and particulate ^{234}Th (Fig. 2). These two stations were occupied at identical positions but were separated in time by approximately three hours. In Fig. 2, we show

data on TSM and POC for both stations. Although the precision on replicate analyses of TSM and POC were poor, it appears that the structure of the water column has been significantly modified even during this short period; therefore, we must doubt the validity of applying a steady state model under these conditions. Nonetheless, the use of this model in the Adriatic Sea provides useful comparative data on scavenging rates and fluxes from the different regions, e.g., northern Adriatic near the Po outflow region compared with the more oligotrophic waters in the Jabuka Pit.

As one of the primary goals of the ELNA project was to estimate fluxes of carbon and other biogenic elements, we have integrated the average fluxes from our scavenging model (P_{Th}) with POC/^{234}Th ratios in surface waters to obtain estimates of the organic carbon flux. Integrating over the surface 20 m, the organic carbon fluxes are about 250 mg C m^{-2} d^{-1} off the Po outflow region (St. 34/36) and about 100 mg C m^{-2} d^{-1} in the Jabuka Pit. The total integrated primary production in these two areas was between 170 and 340 mg C m^{-2} d^{-1} (0-27) and about 400 mg C m^{-2} d^{-1} (0-70 m), respectively (Table 1). Future efforts will concentrate on assessing the quality of these data. It will also be possible to estimate carbon fluxes based on the particulate ^{234}Th and ^{210}Po residence times and POC inventory (available through other ELNA partners) in order to give a more general synopsis of spatial variations in organic carbon fluxes in the Adriatic.

4. Conclusions

The residence times of dissolved ^{234}Th with respect to scavenging onto particles varies between nine and 109 days. Even within the northern and central Adriatic Sea where there is an obvious input of lithogenic particles, scavenging rates appear to show a significant correlation with ^{14}C primary productivity measurements. The residence times of particulate ^{234}Th over much of the study area are relatively short (1-10 days) and indicate that particulate ^{234}Th is being efficiently transported downward. Scavenging and rapid removal of particulate ^{234}Th from the water column is best explained by a mechanism of zooplankton grazing and fecal pellet production. At one sight in the Jabuka Pit, particulate ^{234}Th residence times below the pycnocline are long (30-40 days) suggesting that particles is being more readily recycled at these depths. By comparison, in a seawater profile collected near the Po outflow region, ^{234}Th is depleted with respect to ^{238}U through the entire water column. We conclude from this assessment that particles in shallow waters near the Po River outflow will be more efficiently transported to bottom sediments compared with those in waters over the Jabuka Pit. Based on some preliminary estimates from our scavenging model, the C fluxes in these two regions, integrated over the surface 20 m, are about 250 mg C m^{-2} d^{-1} for the Po outflow region and 100 mg C m^{-2} d^{-1} in the

Jabuka Pit. It would be useful to conduct similar studies on radionuclide scavenging processes in the Adriatic Sea in order to compare fluxes of materials during different seasons.

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Table 1. Summary data on ELNA6 *in-situ* pump stations.

Table 2. Dissolved, particulate and total ^{234}Th, and particulate ^{232}Th concentrations in the Adriatic Sea.

Table 3. Measured and derived parameters associated with an irreversible particle scavenging model under steady state conditions [A_U = ^{238}U activity of sea water; K_d = first order scavenging rate constant for dissolved ^{234}Th with respect to particles (d^{-1}); t = residence times for dissolved (τ^d, days) and particulate ^{234}Th (τ^p, days); and J_{Th} & P_{Th} = ^{234}Th scavenging and particle removal fluxes (units of mBq 1000 L^{-1} d^{-1}).

Fig. 1. Geographical area and location of *in-situ* pump stations.

Fig. 2. Depth distribution of dissolved (A^d), particulate (A^p) and total (A^t) ^{234}Th, uranium (A_U), Chlorophyll a. (Chl. a.), total suspended matter (TSM) and particulate organic carbon (POC) for two stations in the Adriatic Sea.

Fig. 3. ^{234}Th scavenging rates versus primary production for different cell sizes.

Table 1. Summary data on ELNA6 *in-situ* pump stations.

Station No.	Longitude (N)	Latitude (E)	Water depth (m)	Pycnocline depth (m)	Integrated chlorophyll (mg chl. M^{-2})	Integrated primary production (C $m^{-2}d^{-1}$)	Integration depth (m)
St34	44° 48.75	12°47.50	32	11	25	337	25
St. 36	44°48.76	12°48.02	32	13	27	174	27
St. 51	44°12.40	12°48.27	31	18	18	506	30
St. 55	44°26..31	13°13.27	48	20	14	1204	50
St. 66	44°05.20	13°40.99	68	22	8	274	50
St. 71	44°50.59	13°21.17	34	17	16	532	35
St. 74	44°46.20	13°14.55	14	13	7	240	14
St. 87	42°52.64	14°51.59	240	22	12	405	70

Table 2. Dissolved, particulate and total ^{234}Th, and particulate ^{232}Th.

		Radionuclide concentration (mBq l^{-1})			
Sample	**Depth (m)**	**Dissolved ^{234}Th**	**Particulate ^{234}Th**	**Total ^{234}Th**	**Particulate ^{232}Th (ng/l)**
St. 34/36	1	15.7	4.3	20	0.087
	10	23.3	4.2	27.5	0.095
	20	25.7	4.2	30	0.081
	24	14.3	2.7	17	0.026
St. 51	2	12.7	3.2	15.8	0.025
St. 55	14	30.3	2.2	32.5	0.068
St. 66	50	17.3	0.8	18.2	0.054
St. 71	20	26.5	3.3	30.0	0.097
St. 74	5	8.7	6.2	15	0.23
St. 87	10	23.8	2.3	26.7	0.002
	60	23.3	12.5	35	0.012
	80	34.3	4.8	40	0.37

Table 3. Measured and derived parameters associated with an irreversible particle scavenging model under steady state conditions (A_U = ^{238}U activity of sea water; K_d = first order scavenging rate constant for dissolved ^{234}Th with respect to particles (d^{-1}), τ = residence times for dissolved (t^d, days) and particle ^{234}Th (τ^p, days), and J_{Th} and P_{Th} = ^{234}Th scavenging and particle removal fluxes units of mBq 1000 L^{-1} d^{-1}).

Sample	A_U	K_d	τ^d	τ^p	J_{Th}	P_{Th}
St. 34/36						
0 m	41.1	0.048	21	7	729	604
10 m	44.1	0.026	39	9	597	477
20 m	44.4	0.021	47	10	541	417
24 m	44.5	0.063	16	3	861	785
St. 51	44.0	0.071	14	4	901	810
St. 55	44.7	0.014	74	6	414	351
St. 66	44.8	0.045	22	1	791	767
St. 71	44.4	0.020	51	8	513	413
St. 74	41.4	0.11	9	8	914	760
St. 87						
10 m	44.6	0.041	30	5	683	611
40 m	45.1	0.027	39	4	614	533
60 m	45.2	0.023	37	43	628	293
80 m	45.3	0.009	109	32	315	760

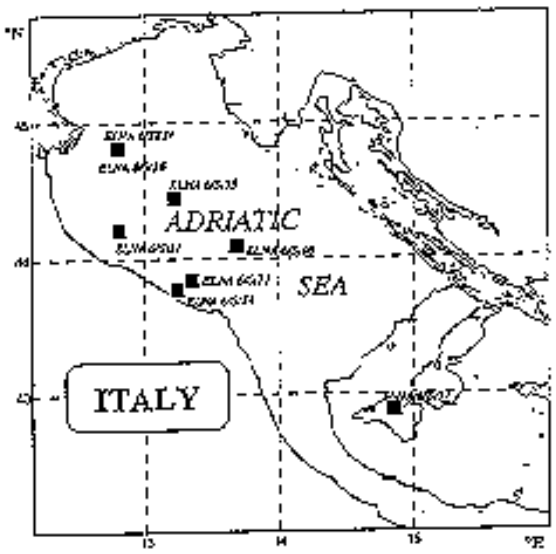

Fig. 1. Geographical area and location of *in-situ* pump stations.

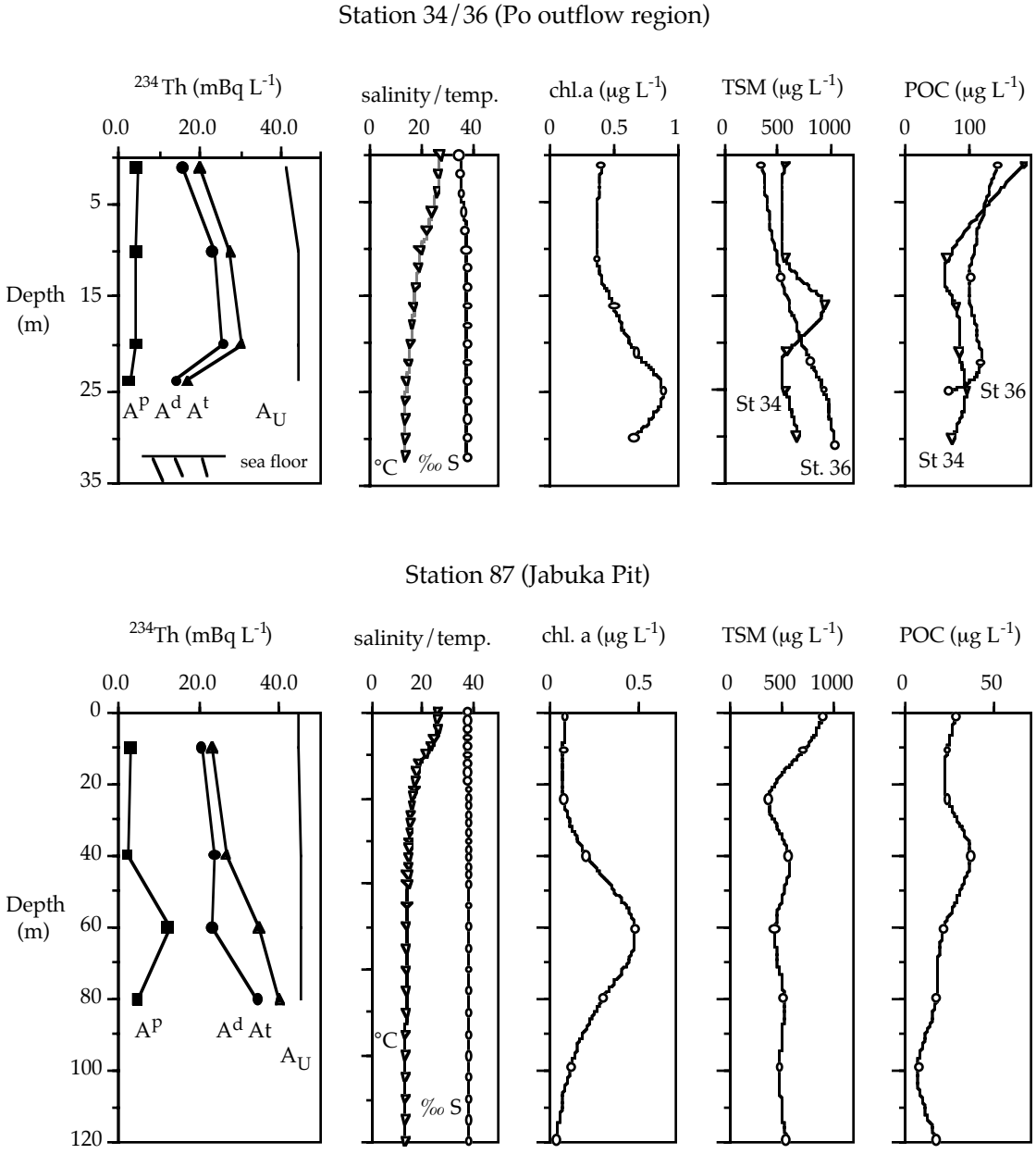

Fig. 2. Depth distribution of dissolved (A^d), particulate (A^p) and total (At) ^{234}Th, uranium (Au), Chlorophyll a. (Chl. a.), total suspended matter (TSM) and particulate organic carbon (POC) for two stations in the Adriatic Sea.

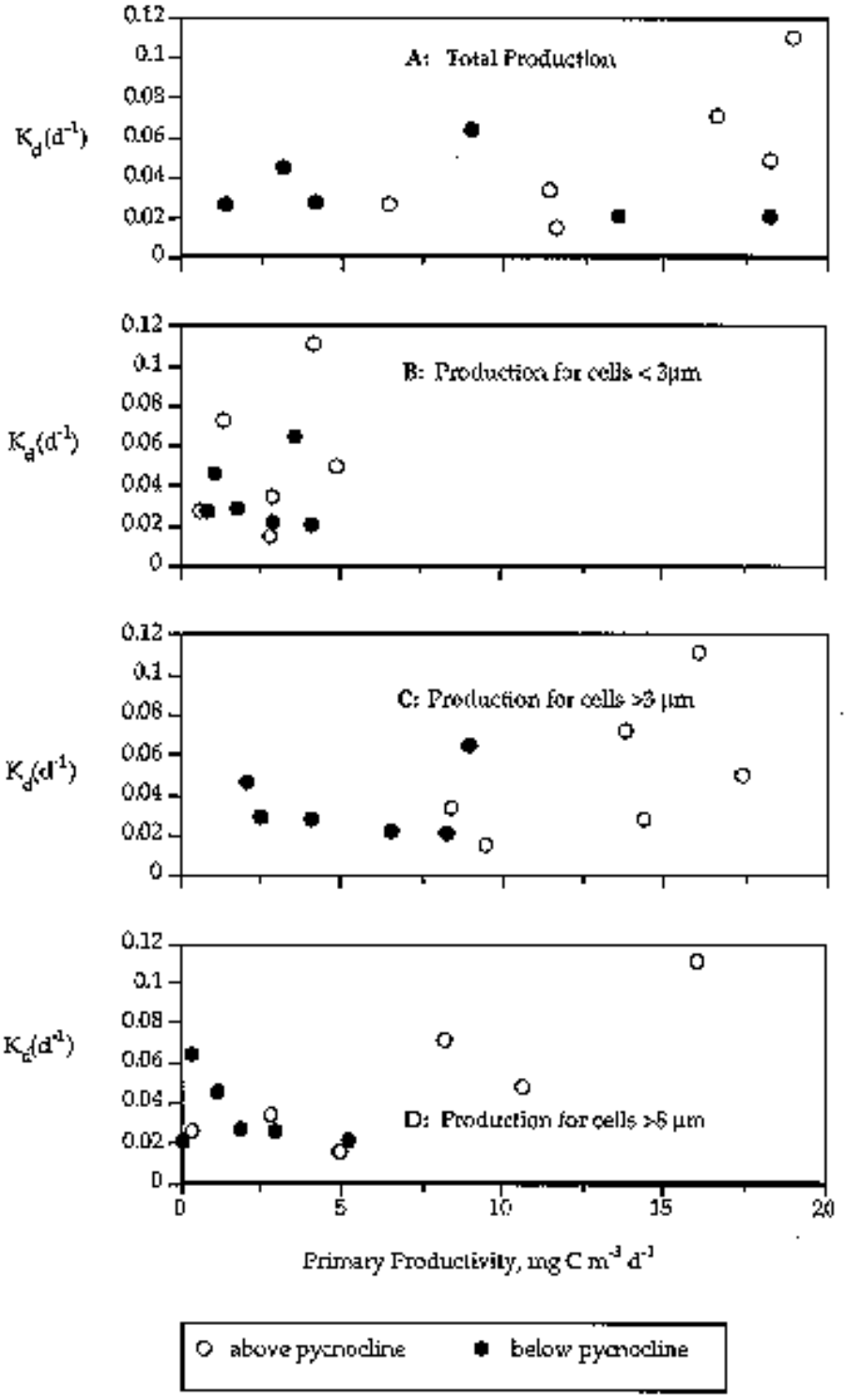

Fig. 3. ^{234}Th scavenging rates versus primary production for different cell sizes.

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