4.4 Heavy metals monitoring in the marine environment by Environmental Protection

---

1. Introduction

In the late 1980s, environmental concerns focussed on the potential human health risk caused by the uptake into the marine biota of toxic trace metals that were thought to be mobilised from the incinerator ash stored at the Waterfront Reclamation site (east of St Aubin's Bay). In July 1993, a study to assess whether any contamination of the marine biota was occurring from the Waterfront Reclamation site commenced. This survey is undertaken by the Fisheries and Marine Resources Section.

The rationale for the survey, the methodology and results are given in a report entitled 'Investigation of possible contamination of marine biota from a land reclamation site at La Collette, Jersey, produced for Fisheries and Marine Resources by Environmental Protection (see Appendix 1).

2. Other monitoring of heavy metals

Environmental Protection have just started collecting baseline data of other potential sources of heavy metal inputs into the marine environment to develop a more comprehensive picture of what is going on in Jersey waters. These include assessment of the heavy metal loading in samples of:

- seawater off the reclamation site at La Collette
- ground/surface water from land drainage (road run-off etc.)
- the discharge from Bellozanne Sewage Treatment Works

Environmental Protection receives regular updates of any new trade effluent consents issued under the Drainage Law. This allows Environmental Protection to assess whether additional regulatory monitoring is required for the Bellozanne Sewage Treatment Works discharge.

The monitoring of heavy metals in the environment will be integral to any waste management licences that are issued by Environmental Protection. In line with best practice, monitoring and reporting will be undertaken by the operator.

3. Constraints

The principal constraint to the monitoring of heavy metals is the cost. At £52 per sample, Environmental Protection need to ensure the sampling is focussed and in line with a robust methodology.

Sampling for heavy metals is an extra activity on top of the team's workload that has not been planned or budgeted for.

The recent dry weather also prohibited sampling of heavy rainfall conditions from outfalls.

Appendix 1 Investigation of possible contamination of marine biota from a land reclamation site at La Collette, Jersey

Dr T. A. du Feu MCiwem, CSci, CEnv, FIFM[1]

Summary

- Levels of six trace metals (mgkg^{-1} dry weight) were determined for two benthic bio-monitors; the common limpet (*Patella vulgata*) and the serrated seaweed (*Fucus serratus)*. Sampling was undertaken up to four times per year between 1993 and 2009 from five sites along the south and south-east coast of Jersey.

- The paper seeks to establish whether any statistical evidence exists that possible contamination from a land reclamation site at La Collette has caused a build up of trace metal contamination in adjacent marine biota.

- A significant correlation existed for all six trace metals between the concentration at La Collette and the two distant sampling sites (Corbiere and Gorey). This suggests that trends recorded at La Collette were evident elsewhere.

- The mean levels of chromium (Cr), lead (Pb) and zinc (Zn) in limpets was significantly higher at La Collette than Corbiere, whilst zinc in *Fucus* was significantly higher at La Collette compared to Gorey.

- However, high levels of these three trace metals also occurred in a nearby coastal sites (West of Albert) suggesting that the source does not originate from La Collette.

- Higher levels of arsenic (As), cadmium (Cd) and zinc in limpets at La Collette were recorded after the date that Crabbe wood mulch was stored there. However, higher concentrations of the three trace metals also occurred at other sampling sites, suggesting that the source is not La Collette.

- Between 1993 and 2009, mean arsenic levels increased in both limpets and *Fucus* at La Collette. This increase also occurred at Corbiere and Gorey and cannot specifically be linked to La Collette. The mean concentration of arsenic recorded for limpets in March 2009 was below the range cited for the Dorset coast.

- Mean recorded cadmium, copper (Cu), lead and zinc levels at La Collette were within the limits cited in literature for limpets and *Fucus* in UK and European waters.

- The analysis presented in the paper provides no statistical evidence that any possible contamination of the sea from the reclamation site at La Collette has resulted in a build up of the six trace metals in the soft tissue of the common limpet or the serrated seaweed within the adjacent coastal area.

1. Introduction

In the late 1980s, environmental concerns focussed on the potential human health risk caused by the uptake into the marine biota of toxic trace metals that were thought to be mobilised from the incinerator ash stored at the Waterfront reclamation site (east of St Aubin's Bay) (Romeril, 1995).

[1] Head of Water Resources, Planning and Environment Department

Benthic molluscs and seaweeds are known to accumulate trace metals into their soft parts and are widely used as bio-monitors of the aquatic environment in contamination and pollution studies (Bryan *et al*.,1977; Bryan & Uysal,1978; Klumpp & Peterson,1979; Miramand & Bentley, 1991; Pearce *et al*.,1997). Metals may be bio-accumulated from solution, suspended particles, sediment, seaweed and phytoplankton and the uptake of metals may differ between species according to their differing feeding patterns (Bryan *et al.* 1980).

The present monitoring programme commenced in July 1993 to assess whether any contamination of the marine biota was occurring from the Waterfront reclamation site. Two benthic mollusc species; the common limpet (*Patella vulgata*), an algal browser; the slipper limpet (*Crepidula fornicata), a filter feeder* and a serrated seaweed (*Fucus serratus)* were used as bio-monitors. All three species were present in large numbers around Jersey's coast.

Previous analysis of the data for 1993 and 1994 concluded that the accumulation of trace metals in the three bio-monitoring species adjacent to the Waterfront reclamation site area was small (Romeril, 1995).

Pearce *et al.* (1997) studied the trace metal chemistry of modern and archaeological limpet shells from Jersey's coastal waters. Results showed no apparent trend of increased trace metal concentration during the life-time of modern limpet specimens. The authors concluded that there was no scientific evidence that any contamination of the sea from the Waterfront reclamation site was producing a build up of trace metal contamination in limpet hard parts.

Concerns of possible leaching of trace metals and the safeguarding of public health have recently been expressed following the ground works for the construction of the Energy from Waste Plant at the reclamation site at La Collette.

The data from the monitoring programme for the Waterfront reclamation site has been used in the present paper to assess whether there is any build up of trace metal contamination in the soft parts of the common limpet (limpet) and *Fucus serratus* (*Fucus*) in the La Collette area as a result of the reclamation site. The La Collette site is adjacent to a designated Ramsar site that extends around the south-east coast.

Key dates for the La Collette site include discussions on the first ash pits in November 1995 and the movement of bailed wood mulch from Crabbe to La Collette in 2003 (Transport and Technical Services *pers. comm*).

The paper assesses data from the Havre des Pas sampling site (being close to the reclamation site and adjacent to the Ramsar designated area) and compares it with two distant sampling sites at Corbiere and Gorey (representing the western and eastern extremities of the sampling sites respectively).

Several recommendations to increase the efficiency and effectiveness of the sampling are included in section 5.

2. Method

2.1 Monitoring programme

Six trace metals (Table I) in the soft parts of limpets and *Fucus* were sampled up to four times per year from initially five sites between July 1993 and March 2009.

Table I Trace metals monitored

Trace element	
Arsenic	As
Cadmium	Cd
Chromium	Cr
Copper	Cu
Lead	Pb
Zinc	Zn

The two species exhibit differing feeding patterns (limpet- algal browser; seaweed-photosynthesis), have limited migration and were present in sufficient numbers at all sampling sites.

Sampling sites included Corbiere, St Aubin, West of Albert, Havre des Pas and Gorey (Fig. 1).

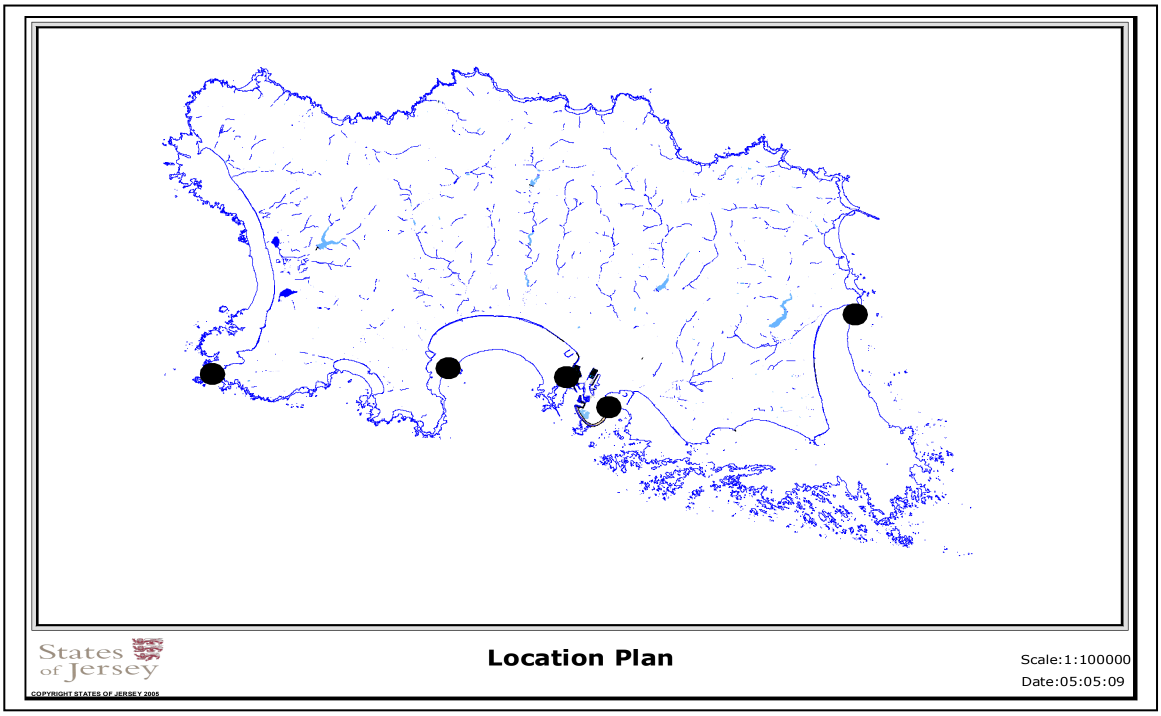


Fig. 1 Sampling sites for common limpet (*Patella vulgata*) and serrated seaweed (*Fucus serratus), 1993-2009*

The paper presents the analysis of data for the limpet and seaweed. Data for the slipper limpet were excluded as the sampling sites were not consistent with, and the data set was not as extensive as, that for the limpet and seaweed.

The Havre des Pas sampling site is located at the seaward side of a rock gulley at the west of the Havre des Pas Bay (Appendix 1). The site is close to the La Collette reclamation site and considered representative of the area. 'Havre des Pas' is thus termed 'La Collette' in the paper. Corbiere and Gorey represent the two sampling sites furthest from La Collette and have been used to compare the La Collette data.

Approximately 40 limpets (30-40mm total length) and 10-15 basal strips (thalli) of *Fucus* were collected during each sampling from the middle to lower shore. Samples were cleaned, combined and analysed by the States of Jersey Official Analyst's Laboratory. Results are expressed as $mgkg^{-1}$ dry weight of soft tissue.

Two extreme outliers were observed in the data set for limpets at La Collette (Pb; 27.1 $mgkg^{-1}$ (15/12/05; 650% higher than the 95% upper CI of the mean) and Cu; 107.1 $mgkg^{-1}$ (23/04/04; 4300% higher than the 95% upper CI of the mean). These were considered not representative of the overall data set and found to mask underlying trends. The two data points were therefore removed prior to analysis.

The paper answers the following questions:

i. Was the overall trend in the concentration of the six trace metals for the two bio-monitors similar between La Collette and both Corbiere and Gorey?
ii. Was the concentration of the six trace metals in both species reported at La Collette significantly different from values recorded at Corbiere and Gorey?
iii. For cases where significant differences existed, did other sampling sites have higher values than La Collette?
iv. Has the concentration of the six trace metals at La Collette changed following specific events (i.e. storage of Crabbe wood mulch)?

3. Results

3.1 Was the overall trend in the concentration of the six trace metals for the two bio-monitors similar between La Collette and both Corbiere and Gorey?

Temporal plots of the concentration of the six trace metals for limpet and *Fucus* are shown in Appendix 2 (comparison of La Collette and Corbiere sampling sites) and Appendix 3 (La Collette and Gorey).

Table II assesses whether the concentration of the trace metals exhibit similar trends (are statistically correlated) between the La Collette site and both Corbiere and Gorey.

The trends recorded at La Collette show significant correlations ($p<=0.10$) with both Corbiere and Gorey for all six trace metals sampled. Observed trends between sites were therefore similar and no site specific trends at La Collette were present (for example, as caused by specific contamination emanating from the La Collette site).

The highest correlation coefficients (Z =0.89 (*Fucus)* & Z=0.88 (limpet)) were recorded for arsenic in *Fucus*. The mean annual concentration of Arsenic in both species at all sampling sites has risen between 1993 and 2009, and particularly between 2005 and 2008 (Figs. 6 & 12). The strong correlation shows that the rise occurred at all three sampling sites and not independently at La Collette.

Table II. Pearson's correlation coefficients (Z and P values) for trace metals recorded in soft tissues of the common limpet and *Fucus serratus* between La Collette and both Corbiere and Gorey. The table shows that a significant correlation (*p*<=0.10) exists for all six trace metals between La Collette and both Corbiere and Gorey.

La Collette compared with Corbiere and Gorey

Limpet	Corbiere, Pearson's correlation coefficient (Z)	*p* value	Gorey Pearson's correlation coefficient (Z)	*p* value
Arsenic	0.58	*0.00*	0.88	*0.00*
Cadmium	0.31	*0.03*	0.47	*0.00*
Chromium	*0.27	*0.10*	*0.33	*0.01*
Copper	0.36	*0.01*	0.39	*0.00*
Lead	0.54	*0.00*	0.47	*0.00*
Zinc	0.44	*0.01*	0.75	*0.00*
Fucus				
Arsenic	0.76	*0.00*	0.89	*0.00*
Cadmium	0.37	*0.00*	0.54	*0.00*
Chromium	0.44	*0.02*	0.52	*0.00*
Copper	0.36	*0.01*	0.55	*0.00*
Lead	0.48	*0.00*	0.34	*0.02*
Zinc	0.56	*0.00*	0.73	*0.00*

* Kendal's nonparametric correlation coefficient

3.2 Was the concentration of the six trace metals in both species reported at La Collette significantly different from values recorded at Corbiere and Gorey?

Section 3.1 shows that a strong relationship existed between the trends within differing sampling sites. However, the La Collette site may exhibit significantly higher or lower levels of detected trace metals than Corbiere or Gorey (i.e. the same trend but at differing levels).

Table III and Appendix 2 & 3 further explore the relationship of trace metals in both species between sites and assesses whether any significant difference in the mean concentration of trace metals between sites exists.

The mean concentration of zinc was significantly higher at La Collette than Corbiere for both limpets and *Fucus*. Chromium and lead in limpets was also significantly higher at La Collette than Corbiere, and the concentration of zinc in *Fucus* was significantly higher at La Collette compared to Gorey (Table III).

Overall mean values recorded at La Collette are within the majority of the range of values reported in literature for limpets and *Fucus* in UK and European seawaters (Appendix 5).

Table III: Mean and standard deviation of the concentration of trace metals at La Collette, Corbiere and Gorey. Significantly higher levels of chromium, lead and zinc were detected at La Collette compared with Corbiere for the common limpet. Whilst *Fucus* had higher levels of zinc at La Collette compared with Gorey.

Limpet	Mean conc. La Collette ($mgkg^{-1}$)	Std	Mean conc. Corbiere ($mgkg^{-1}$)	Std	Mean conc. Gorey ($mgkg^{-1}$)	Std
Arsenic	7.5	*4.4*	8.9	*6.8*	8.9	*5.1*
Cadmium	5.2	*1.2*	9.1	*2.7*	6.0	*2.3*
Chromium	1.8	*0.9*	1.1	*0.7*	1.6	*1.0*
Copper	8.3	*7.8*	9.3	*8.6*	7.0	*4.2*
Lead	3.6	*1.7*	2.8	*1.7*	3.1	*1.5*
Zinc	101.4	*29.6*	86.2	*33.2*	94.4	*31.6*
Fucus						
Arsenic	41.3	*21.7*	41.1	19.0	39.5	*22.2*
Cadmium	1.0	*0.4*	1.5	0.4	1.1	*0.5*
Chromium	0.8	*0.3*	0.7	0.5	0.7	*0.4*
Copper	4.1	*1.9*	4.9	4.2	3.8	*2.4*
Lead	2.7	*1.6*	2.4	2.1	2.5	*2.3*
Zinc	55.5	*23.3*	43.4	22.9	43.6	*23.0*

Median values for non-parametric data; Chromium in limpets 1.8 (La Collette); 0.9 (Corbiere) & 1.5 (Gorey)

55.5 (orange)	Mean levels significantly higher at La Collette than at Corbiere (Cr, Wilcoxen signed rank test, *p*=0.00; Pb, Student paired t-test, *p*=0.00; Zinc. Student paired T-test, *p*=0.03 (limpet) and *p*=0.00 (Fucus)).
55.5 (green)	Mean levels significant higher at La Collette than both Corbiere and Gorey (Zn; Student t-test, *p*=0.00).
55.5 (yellow)	Mean levels significant higher at Corbiere or Gorey than at La Collette

3.3 For cases where significant differences exist, did other sites have higher values than La Collette?

Table IV further investigates the significant differences identified in section 3.2, by assessing whether the significantly higher levels were recorded only at La Collette or whether they existed in other sampling sites. Higher levels occurring elsewhere would suggest that the contamination is not arising from the La Collette area.

Significantly higher ($p<=0.05$) mean levels of chromium in both limpets and *Fucus* were also recorded at the West of Albert sampling site compared with levels at La Collette (Table IV). Zinc in limpets was also significantly higher, and lead higher (not significant), at the West of Albert site compared with La Collette. Examination of the mean annual data (Appendix 4) shows that the higher levels were generally consistent throughout the sampling period and not as a result of short-term rises.

Table IV. Comparison of the mean concentration (mgkg^{-1} dry weight) and the level of significance (*p* value) between all five sampling sites and La Collette of trace metals. The table shows that high concentrations of trace metals were not solely confined to La Collette.

Limpet- Chromium	Mean concentration (mgkg^{-1})	Std	*p* value, level of significant difference of the mean from La Collette *Wilcoxen signed rank test**	Z value (non-parametric data)
La Collette	*1.8*	*0.9*	-	-
Corbiere	1.1	*0.7*	**0.00**	-4.27
Gorey	1.6	*1.0*	0.08	-1.73
St Aubin	1.8	*1.2*	0.37	-0.89
West of Albert	2.1	*1.2*	**0.01**	-2.45
Fucus - Chromium			*Student paired t-test*	df value (parametric data)
La Collette	*0.8*	*0.3*	-	-
Corbiere	0.7	*0.5*	0.27	46
Gorey	0.7	*0.4*	0.62	45
St Aubin' s Bay	0.9	*0.7*	0.22	46
West of Albert	1.1	*0.9*	**0.02**	43
Limpet - Zinc				df value
La Collette	*101.4*	*29.6*	-	
Corbiere	86.2	*33.2*	**0.03**	48
Gorey	94.4	*31.6*	**0.05**	47
St Aubin's Bay	102.5	*32.8*	0.66	48
West of Albert	112.6	*37.8*	**0.01**	46
Fucus - Zinc				df value
La Collette	*55.5*	*23.3*	-	
Corbiere	43.4	*22.9*	**0.00**	50
Gorey	43.6	*23.0*	**0.00**	49
St Aubin's Bay	50.0	*25.9*	0.08	50
West of Albert	64.8	*35.3*	0.07	47
Limpet - Lead				df value
La Collette	*3.6*	*1.7*	-	
Corbiere	2.8	1.7	**0.02**	48
Gorey	3.1	1.5	**0.02**	47
St Aubin's Bay	3.0	1.5	0.07	48
West of Albert	3.7	1.9	0.51	46
***Fucus* - Lead**				df value
La Collette	*2.7*	*1.6*	-	
Corbiere	2.4	2.1	0.24	50
Gorey	2.5	2.3	0.89	50
St Aubin's Bay	2.6	1.9	0.47	50
West of Albert	2.9	2.5	0.50	47

Number in bold indicate mean is significantly different (at p<=0.05) from the La Collette site

3.4 Has the concentration of the six trace metals at La Collette changed following specific events (i.e. storage of Crabbe wood mulch)?

Storage of wood mulch from Crabbe commenced at La Collette in September 2003. Table V shows the mean and standard deviation values before and after this period and highlights whether the post wood mulch data resulted in any significant change (including data for the slipper limpet).

The mean concentration of trace metals was lower after wood mulch was stored at La Collette for the majority of trace metals. The exception was arsenic (all species), cadmium (limpet) and zinc (limpet). The level of arsenic was significantly higher post storage of wood mulch for all species (p=0.00, Z=-8.5 (limpet); p=0.00, Z=-6.4 (*Fucus*); p=0.00, Z=-0.28 (slipper limpet), Mann-Whitney test for non-parametric data) and significantly different for zinc in limpets (p=0.00, df=129, t-test for unequal variance). The rise in cadmium levels in limpets was not significantly different (p=0.08, Z=-1.76, Mann-Whitney test).

Table V. Mean values and standard deviation of the concentration of trace metals (mgkg^{-1} dry weight) at La Collette for the pre and post storing of Crabbe wood mulch (before 01/09/2003 and after 01/09/2003 resp.). Mean levels that were significantly higher during post storage of wood are given in bold.

Trace metal	Limpet				*Fucus*				Slipper limpet			
	Pre wood mulch		Post wood mulch		Pre wood mulch		Post wood mulch		Pre wood mulch		Post wood mulch	
	Mean	*Std*	Mean	*Std*	Mean	*Std*	Mean	*Std*	Mean	*Std*	Mean	*Std*
Arsenic	5.9	*3.5*	**10.4**	*4.4*	34.5	*18.0*	**53.2**	*23.1*	8.3	*6.2*	**11.1**	*4.5*
Cadmium	5.2	*1.0*	5.3	*1.5*	1.0	*0.3*	1.0	*0.5*	1.0	*1.7*	0.7	*1.1*
Chromium	1.8	*0.9*	1.8	*1.0*	0.8	*0.3*	0.7	*0.3*	1.7	*1.2*	1.3	*0.6*
Copper	10.2	*8.9*	4.4	*1.9*	4.8	*1.8*	2.6	*1.1*	36.9	*10.9*	28.6	*11.5*
Lead	4.0	*1.9*	3.0	*1.3*	3.0	*1.5*	2.2	*1.6*	2.9	*1.2*	2.7	*3.2*
Zinc	100.9	*31.0*	**102.3**	*27.6*	56.3	*26.0*	53.9	*17.2*	81.7	*27.7*	78.2	*39.9*

4. Discussion

A monitoring programme was undertaken between 1993 and 2009 to assess possible contamination of adjacent marine biota from the storage of incinerator ash at the Waterfront reclamation site (east of St Aubin's Bay). The paper uses the data set to assess the same hypothesis, but relating to a subsequent land reclamation site at La Collette.

Two marine bio-monitors exhibiting differing feeding regimes and five sampling sites located throughout the south and south-east coast were sampled. The Havre des Pas sampling site, is close to, and considered representative of, the La Collette reclamation site.

The common limpet and *Fucus serratus* are widely used as bio-monitor species of trace metals (Bryan *et al.*,1977; Bryan & Uysal,1978; Klumpp & Peterson,1979; Miramand & Bentley, 1991; Pearce *et al.*,1997). The analysis of the data for these two species is presented in the paper.

The methodology of the study and the resultant long-term data set is considered robust to answer whether possible contamination of the marine biota has occurred as a result of the La Collette reclamation site.

A significant correlation existed between the concentration of separate trace metals in limpets and *Fucus* at La Collette and the two distant sampling sites (Corbiere and Gorey). This suggests that no localised pollution from the La Collette reclamation site has taken place.

In theory, positive correlations can exist between sites but may mask overall data that are higher or lower than other areas. Significant differences between sites were therefore determined.

The mean concentration at La Collette of chromium, lead and zinc were all significantly higher in limpets (and also *Fucus* for zinc) than Corbiere. However, apart from zinc no significant difference was noted for the concentration of these elements between La Collette and Gorey. Conversely, the mean concentration of cadmium was significantly higher at Corbiere than La Collette for both limpets and *Fucus* (and also at higher Gorey for limpets). Arsenic levels were also significantly higher at Gorey compared to La Collette.

Comparison of the concentration of these trace metals in neighbouring sites indicates that significantly higher levels existed at the West of Albert sampling site. This suggest that the source of these trace metals is not La Collette. Examination of the annual data (Appendix 4) shows that these higher levels were generally consistent throughout the sampling period and not as a result of short-term rises.

Comparison with values cited for other UK and European seawaters (Appendix 5) indicate that zinc and copper in limpets was higher at La Collette than neighbouring French waters (Miramand & Bentley, 1991) and the Irish Sea (Segar *et al.* 1971)and that cadmium was higher at the Weymouth and Devon coast (Langston *et al*, 2003; Bryan & Hummerstone, 1977). Copper and lead were higher in Fucus for neighbouring French waters compared to La Collette (Miramand & Bentley, 1991). Overall, the mean values reported for La Collette are within ranges cited elsewhere for UK and European seawaters.

High levels of zinc, chromium and lead were recorded at the West of Albert site compared to La Collette. The site is closest to the Weighbridge outfall that drains a large catchment (including large parts of St Helier) and the outfall from the Island's sewage treatment works (Bellozanne outfall).

It is difficult to assign probable sources to these trace metals. However, the proximity of the West of Albert site to the above land drainage outfalls suggest that the sources are land based. Langston *et al*. (2003) concur with the influence of land drainage and recognised the influence of the Weighmouth outfall for limpets collected in Portland, UK.

Martin & Meybeck (1979) note that zinc is one of the most ubiquitous and mobile of heavy metals and is transported both in dissolved form and associated with particulate matter. Possible sources of zinc include zinc naturally occurring in the soil, from tyres and brakes (via road run-off), zinc anodes (which are present in the nearby boat marina) and galvanised roofs.

The origin of chromium is unclear. Mance *et al*. (1979) recognised that sewage may contain 100 $\mu g l^{-1}$ chromium, however the major source in such cases is normally discharges from electroplating activities. Sewage from Bellozanne will contain a background level of chromium. Other sources may include exhaust emissions from chromium based catalytic converters and wood preservatives.

Possible sources of lead may include historic emissions from lead based fuel which settled in soils and are still being leached out, lead pipe work and run-off from lead roofs.

The analysis shows that levels of arsenic in both limpets and *Fucus* have risen at all sites since 1993, with 2008 levels at La Collette being 17.0 and 95.6mgl^{-1} respectively. Lead arsenate was used to control colorado beetle in the early 1900s and mixture of lead arsenate and copper oxide was used to control both the beetle and potato blight during the 1940s and 50s. The date that arsenic was last used is not known. Some arsenic products are also used for wood preservative (Env. Monit. Working Group, 2000).

Arsenic occurs in several inorganic forms in sea water which exhibit differing toxicity behaviour in marine flora and fauna. Mance *et al*. (1984) considered that accumulation of arsenic is in the form of relatively innocuous organo-arsenic compounds, however they concluded that there is not enough evidence for complacency.

It is unclear whether the increase in arsenic levels in limpets and *Fucus* along the south coast is as a consequence to land and beach application post 1940s. The level although having increased is below levels reported for Portland by Langston *et al.* (2003).

Data for the slipper limpet was briefly analysed in order to cross-check the main conclusions presented in the paper. The mean concentration of arsenic in slipper limpets at La Collette was higher than recorded for the common limpet (9.5 mgkg^{-1} (std: 5.6) compared to 7.5 mgkg^{-1} (std: 4.4)). However, like the common limpet, higher mean levels for the slipper limpet were recorded at other sampling sites (for example, 11.7 mgkg^{-1} (std: 11.3) at Elizabeth Castle).

Copper was also higher in the slipper limpet compared to the common limpet at La Collette (33.3 mgkg^{-1} (std: 11.7) compared to 8.3 (std: 7.8). Again, higher levels of copper for slipper limpets were observed at other sampling sites (for example, 69.4 mgkg^{-1} (std: 29.6) at Elizabeth Castle). Thus, the data for the slipper limpet confirms findings for the limpet and *Fucus*, that although levels of two trace metals were higher at La Collette, they were even higher at other sampling sites.

The lack of a relationship between potential source and receptor (La Collette reclamation site and selected marine biota) has also been observed by Miramand & Bentley (1991) who sampled limpets and *Fucus* 15km from the outlet of the nuclear reprocessing plant at Cap de la Hague. The authors reasoned that any metal contamination would be dispersed by the large tidal flows.

The current analysis presented in the paper indicates that there is no statistical evidence that possible contamination from the La Collette site has increased the trace metal concentration in the common limpet or *Fucus* seaweed in the adjacent area. High tidal flows are present along the coast of Jersey, however comparison with results cited elsewhere, indicates that all values are within common ranges. This suggests that contamination across a wider area is not occurring.

5. Recommendations

1. Identify a mixed open water control site for sampling that is distant from Jersey

2. Review current sampling sites

3. Review sampling frequency

4. Review the trace elements analysed in light of recent composition data of incinerator ash

5. Closely monitor the increase in arsenic

6. Produce a brief annual summary of results

7. Publish current findings for peer review and wider dissemination

6. References

Bryan, G.W. & L.G. Hummerstone, 1977. Indicators of heavy metal contamination in the Looe Esturay (Cornwall) with particular regard to silver and lead. *J. Mar. Biol. Assoc.* **57**: 75-92.

Bryan, G.W., G.W. Potts, & G.R. Forster. 1977. Heavy metals in the gastropod mollusc *Haliotis tuberculata* (L.). *J. Mar. Biol. Assoc. UK.*, **57**: 379-390.

Bryan, G.W. & H. Uysal. 1978. Heavy metals n the burrowing bivalve *Scrobicularia plana* from the Tamar estuary in relation to environmental levels. *J. Mar. Biol. Assoc. UK.* **58**: 89-108.

Bryan, G.W., Langston, W.J. & L.G. Hummerstone. 1980. The use of biological indicators of heavy metal contamination in estuaries with specific reference to an assessment of the biological availability of metals in estuarine sediments form south-west Britain. *J. Mar. Biol. Assoc* . Occ. pap.1: 1-73.

Dutton, J., D.F. Jefferies., A. Folkard & P Jones. 1973. Trace metals in the North Sea. *Mar. Pollut. Bull*. **4**: 135-138.

Environmental Monitoring Working Group. 2000. Arsenic levels in soil. *An internal paper of the Environmental Monitoring Working Group, States of Jersey.* 7p.

Foster, P. 1976. Concentrations and concentration factors of heavy metals in brown algae. *Environ. Pollut*. **10**: 45-53.

Fuge, R. & K.H. James. 1974. Trace metal concentrations in *Fucus* from the Bristol Channel. *Mar. Pollut. Bul.* **5**: 9-12.

Klumpp, D.W. & P.J. Peterson, 1979. Arsenic and other trace elements in the waters and organisms of an estuary in S.W. England. *Environ. Pollut*, **19**: 11-20.

Lande, E. 1977. Heavy pollution in Trondheimfjorden, Norway and the recorded effects on fauna and flora. *Environ. Pollut.* **12**: 187-198.

Langston, W.J, Chesman, B.S., Burt, G.R., Hawkins, S.J., Readman, J., & P.Worsfold, 2003. Site characteristic of the south west European marine sites. Chesil and The Fleet. *Mar. Biol. Assoc. Occ. Pap* 11: 168p.

Leatherland, T.M & Burton, J.D. 1974. The occurrence of some trace metals in coastal organisms with particular reference to the Solent Region. *J. Mar. Biol. Ass.* **54**: 457-468.

Mance, G., C. Musselwhite & V.M. Brown. 1984. Proposed environmental quality standards for list II substances in water – arsenic. *Water Research Centre Technical Report*, TR 212. 51p.

Martin, J.M. & M. Meybeck. 1979. Elemental mass balance of material carried by major world rivers. *Marine Chemistry*. **7**: 173-206.

Miramand, P & Bentley, D. 1991. Heavy metal concentrations in two biological indicators (*Patella vulgata* and *Fucus serratus*) collected near the French nuclear fuel reprocessing plant at La Hague. *The Science of the Total Environment*, **111**: 135-149

Pearce, N., Wyer, M. & D. Kay, 1997. Trace element chemistry of modern and archaeological limpet shells from Jersey and environs. *Report to the States of Jersey*.

Preston, A. Jefferies, D.F, Dutton, J.W.R, Harvey, B.R & A.K. Steele. 1972. British Isles coastal waters: The concentration of selected heavy metals in sea water, suspended matter and biological indicators- a pilot survey. *Environ. Pollut*. **3**: 68-82.

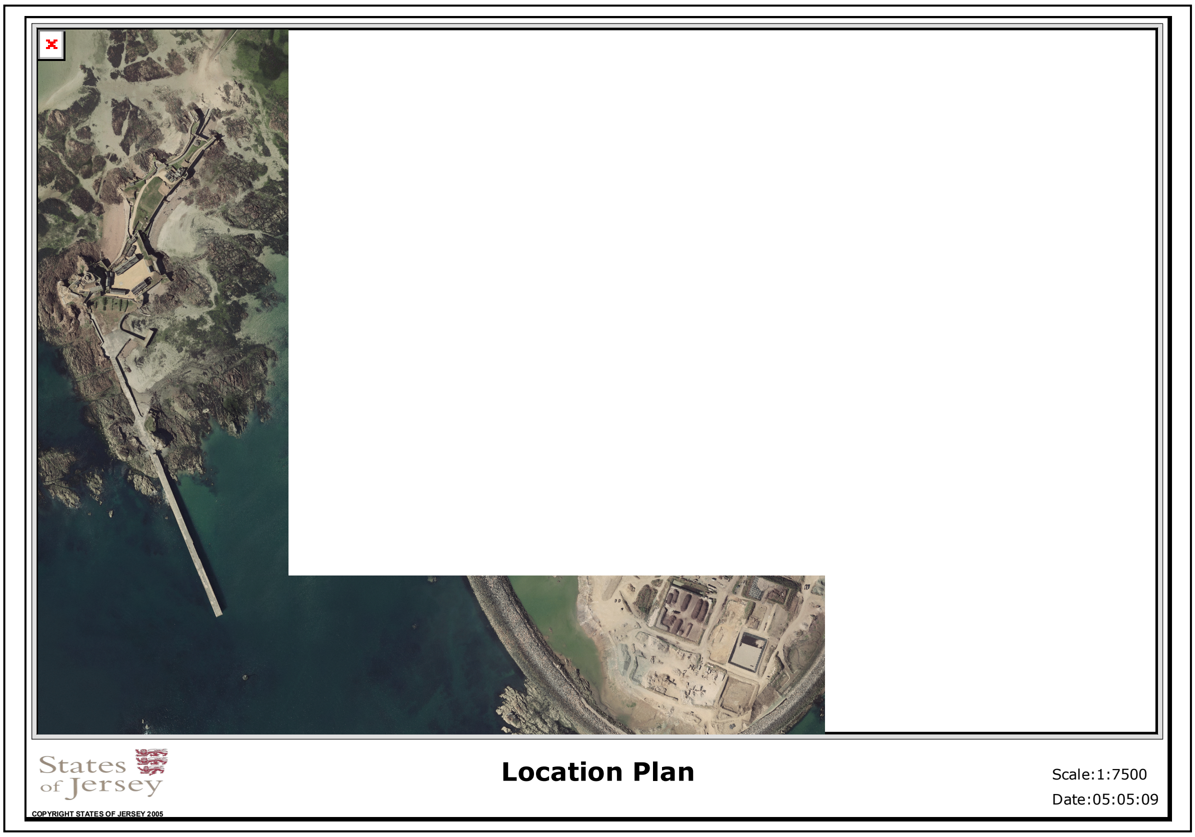
Romeril, M. (1995). Marine heavy metal monitoring programme. *States of Jersey Report*. 10p

Segar, D.A, J.D. Collins and J.P. Riley, 1971. The distribution of the major and some minor elements in marine mammals. Part II. Molluscs. *J. Mar. Biol. Assoc. UK*. **51**: 131-136.

Söderlung, S.A., Forsberg, A & M. Pedersén. 1988. Concentration of cadmium and other metals in *Fucus vesiculosus* L. and *Fontinalis dalecarlica* Br. Eur. from the northern Baltic Sea and the southern Bothnian Sea. *Environ. Pollut.* **51**: 197-212.

Appendix 1

Location of the La Collette and West of Albert sampling sites for common limpet (*Patella vulgata*) and serrated seaweed (*Fucus serratus)* sampling, *1993-2009*



West of Albert La Collette

Appendix 2: Comparison of La Collette and Corbiere sampling sites

Cadmium

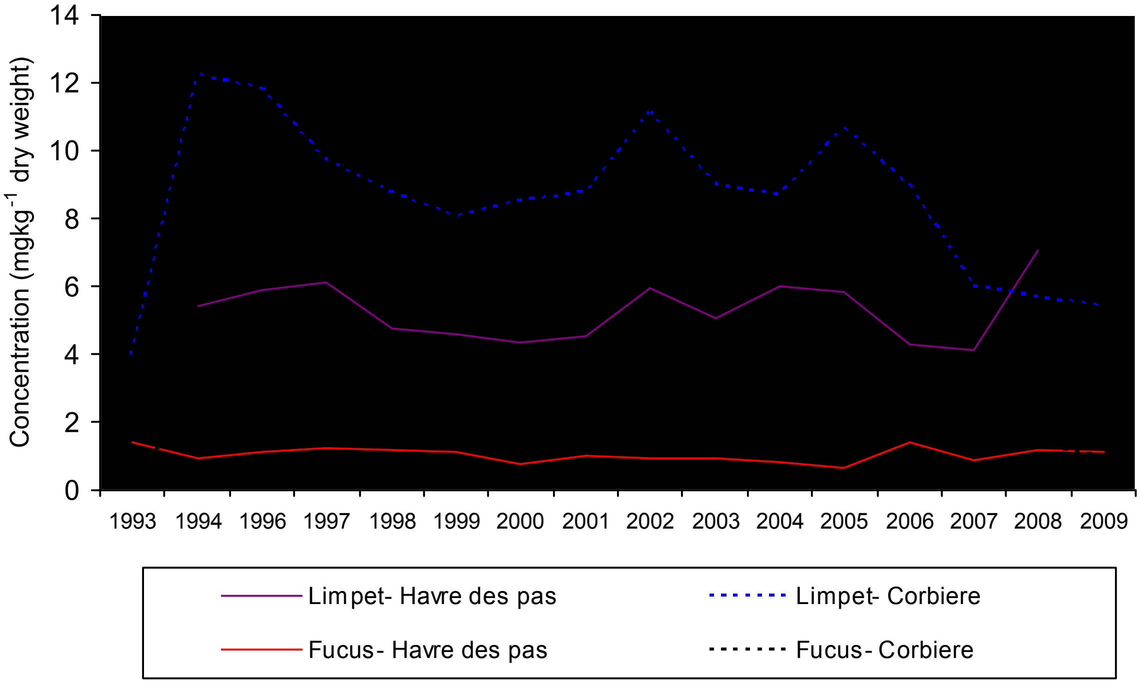


Fig. 1: Mean annual concentration (mgkg^{-1} dry weight) of cadmium (Cd) in the common limpet (*Patella vulgata*) and *Fucus serratus* seaweed at Havre des Pas (La Collette) and Corbiere. The concentration of cadmium in limpets and *Fucus* was significantly higher at Corbiere than La Collette (Student paired t-test, p=0.00, df=48 (limpet), Student paired t-test, p=0.00, df=50 (*Fucus*)).

Lead

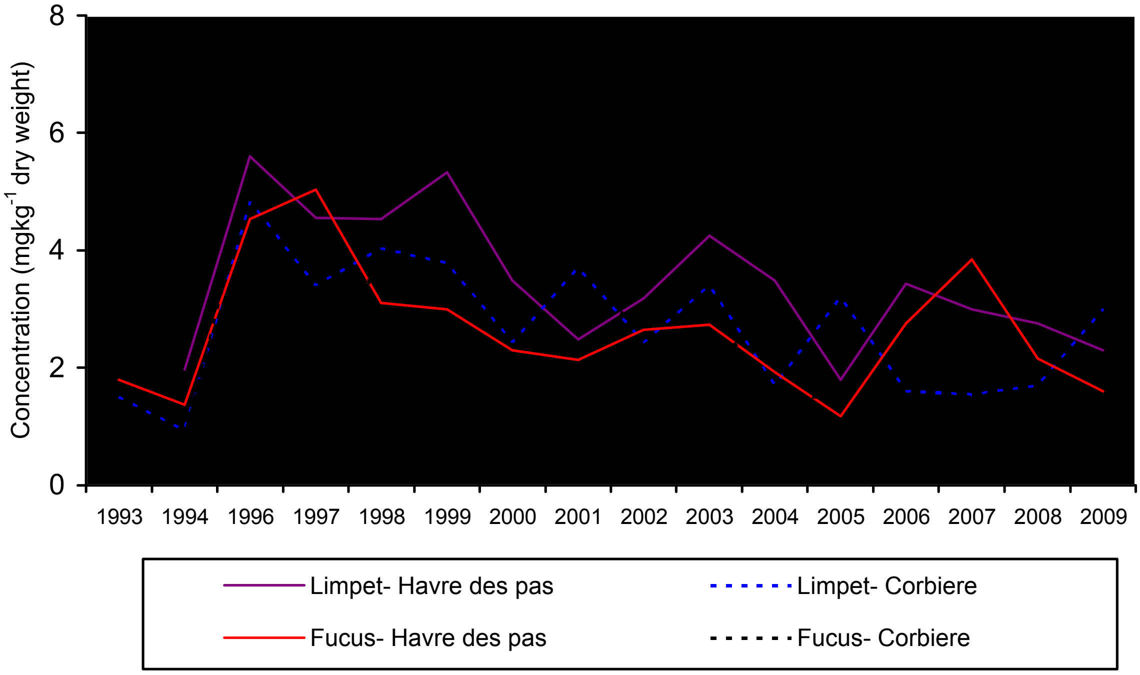


Fig. 2: Mean annual concentration (mgkg^{-1} dry weight) of lead (Pb) in the common limpet (*Patella vulgata*) and *Fucus serratus* seaweed at Havre des Pas (La Collette) and Corbiere. The concentration of lead in limpets was significantly higher at La Collette (Student paired t-test, p=0.00, df=48). No significant difference existed between Corbiere and La Collette for *Fucus* (Student paired t-test, p=0.24, df=50. Note: an extreme outlier value of 27.1 mgkg^{-1} reported on 15/12/05 for limpets at La Collette was omitted from the analysis.

Copper

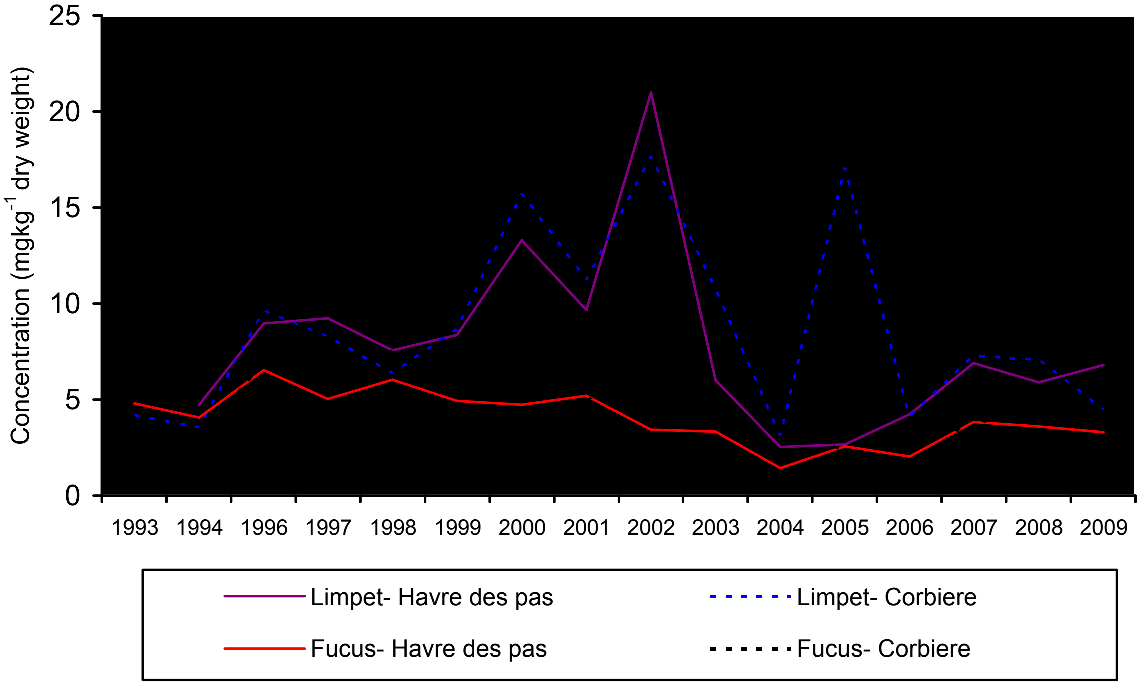


Fig. 3: Mean annual concentration (mgkg^{-1} dry weight) of copper (Cu) in the common limpet (*Patella vulgata*) and *Fucus serratus* seaweed at Havre des Pas (La Collette) and Corbiere. The concentration of copper in limpets and *Fucus* was not significantly higher at La Collette than Corbiere (Student paired t-test, p=0.38, df=48 (limpet), Student paired t-test, p=0.12, df=50 (*Fucus*)). Note: an extreme outlier value of 107.1 mgkg^{-1} reported for 23/04/04 for limpets at La Collette was omitted from the analysis.

Zinc

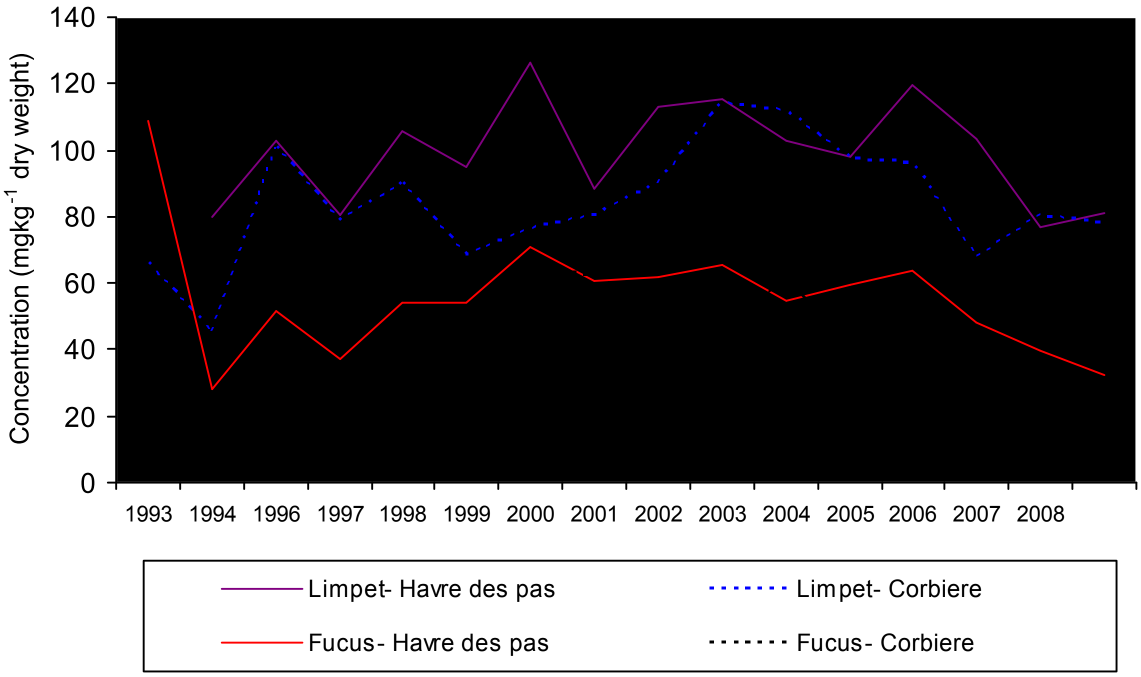


Fig. 4: Mean annual concentration (mgkg^{-1} dry weight) of zinc (Zn) in the common limpet (*Patella vulgata*) and *Fucus serratus* seaweed at Havre des Pas (La Collette) and Corbiere. The concentration of zinc in limpets and *Fucus* was significantly higher at La Collette (Student paired t-test, p=0.03, df=48 (limpet) Student paired t-test, p=0.00, df=50 (*Fucus*).

Chromium

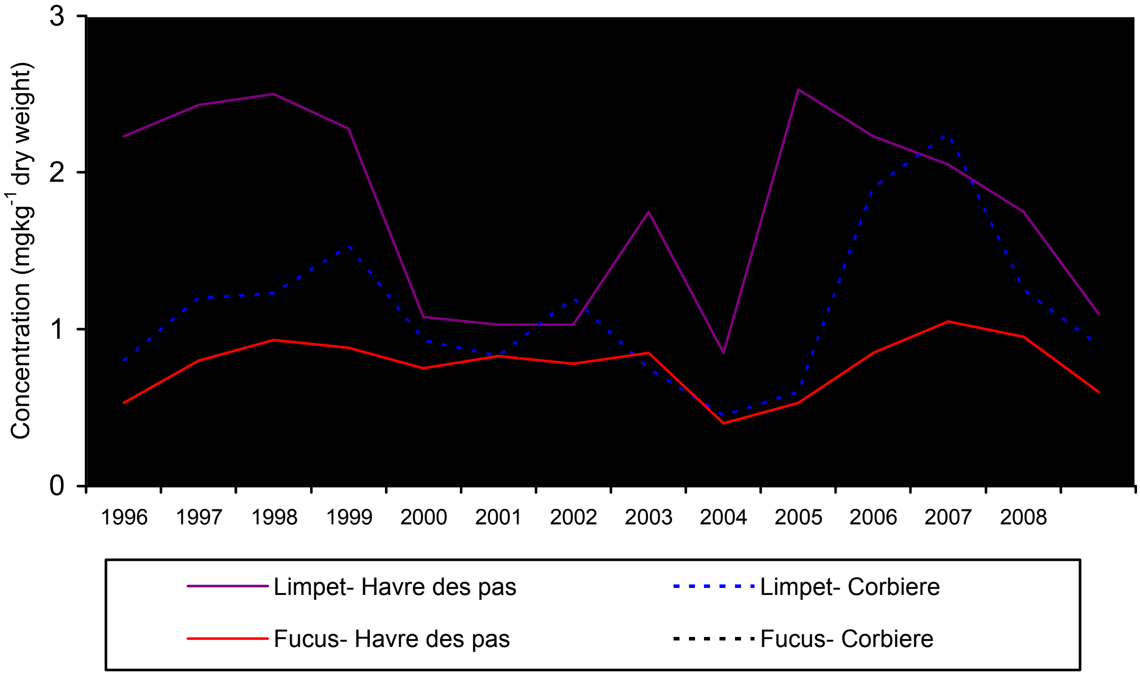


Fig. 5: Mean annual concentration ($mgkg^{-1}$ dry weight) of chromium (Cr) in the common limpet (*Patella vulgata*) and *Fucus serratus* seaweed at Havre des Pas (La Collette) and Corbiere. The concentration of chromium in limpets was significantly higher at La Collette (Wilcoxen signed rank test, *p*=0.00, Z=-4.27. No significant difference existed between Corbiere and La Collette for *Fucus* (Student paired t-test, *p*=0.27, *df*=50.

Arsenic

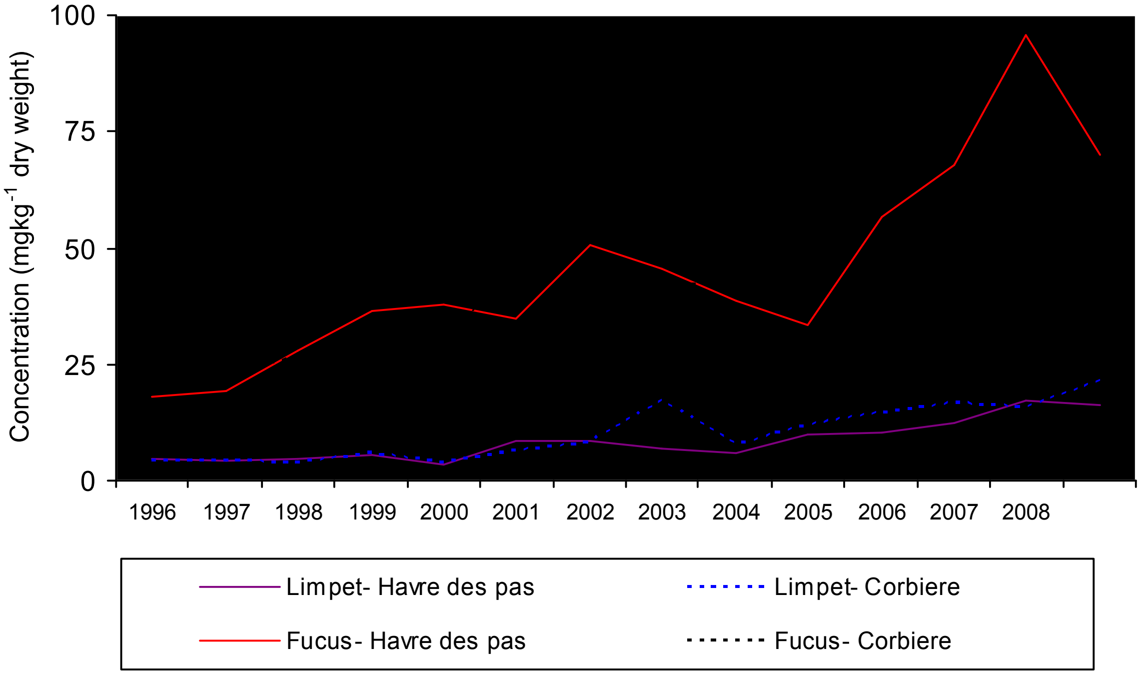


Fig. 6: Mean annual concentration ($mgkg^{-1}$ dry weight) of arsenic (As) in the common limpet (*Patella vulgata*) and *Fucus serratus* seaweed at Havre des Pas (La Collette) and Corbiere. No significant difference existed between the two sites (Student paired t-test, *p*=0.08, *df*=45 (limpet), Student paired t-test, *p*=0.93, *df*=46 (*Fucus*)).

Appendix 3: Comparison of La Collette and Gorey sampling sites

Cadmium

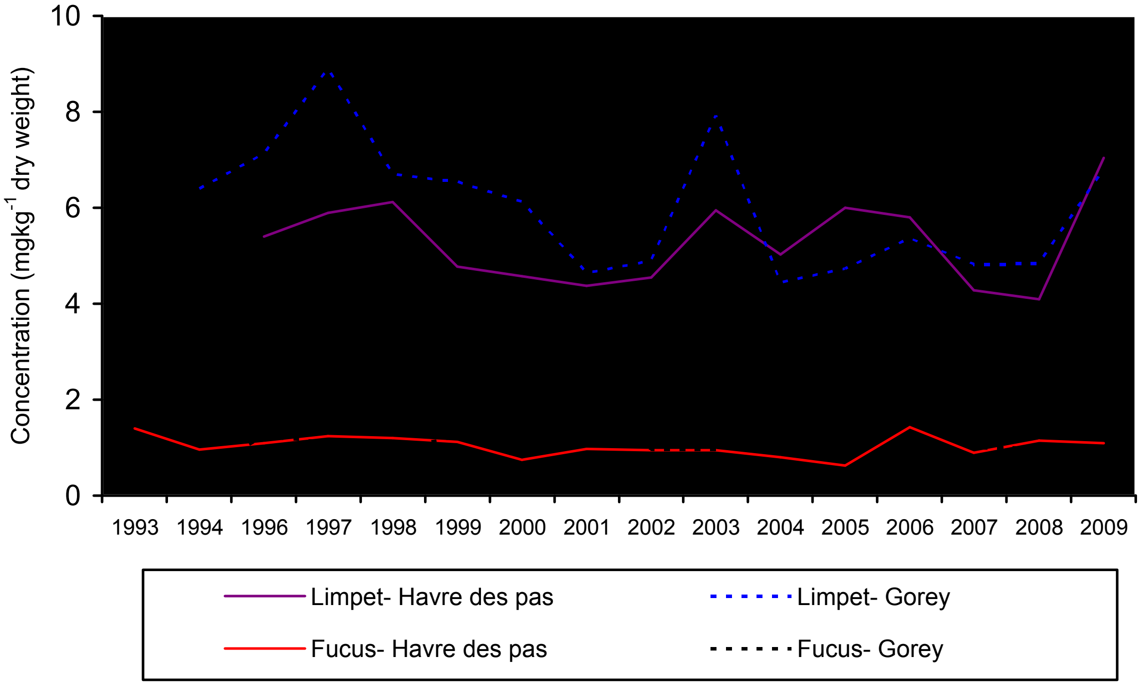


Fig. 7: Mean annual concentration (mgkg^{-1} dry weight) of cadmium (Cd) in the common limpet (*Patella vulgata*) and *Fucus serratus* seaweed at Havre des Pas (La Collette) and Gorey. The concentration of cadmium in limpets is significantly higher at Gorey than La Collette (Student paired t-test, *p*=0.14, df=47). No significant difference exists between the mean concentration of cadmium in *Fucus* at La Collette and Gorey (Student paired t-test, *p*=0.45, df=49).

Lead

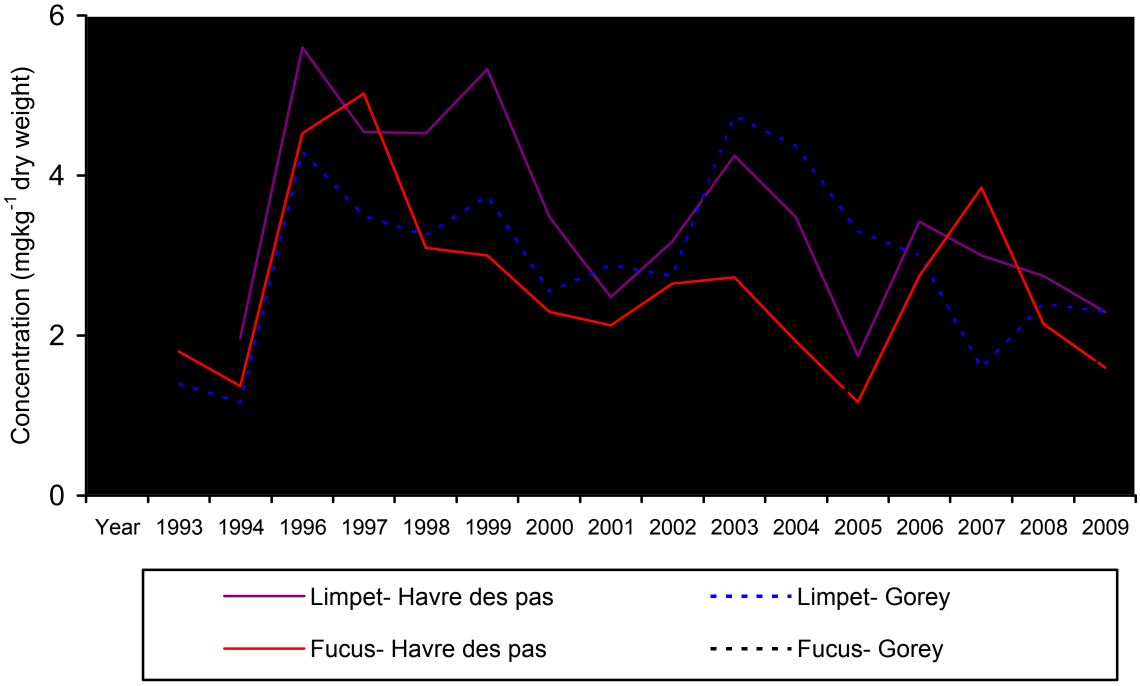


Fig. 8: Mean annual concentration (mgkg^{-1} dry weight) of lead (Pb) in the common limpet (*Patella vulgata*) and *Fucus serratus* seaweed at Havre des Pas (La Collette) and Gorey. No significant difference exists between the mean concentration of lead in limpets or *Fucus* at La Collette and Gorey (Student paired t-test, *p*=0.06, df=48 (limpet) and *p*=0.44, df=49 (*Fucus*)).

Copper

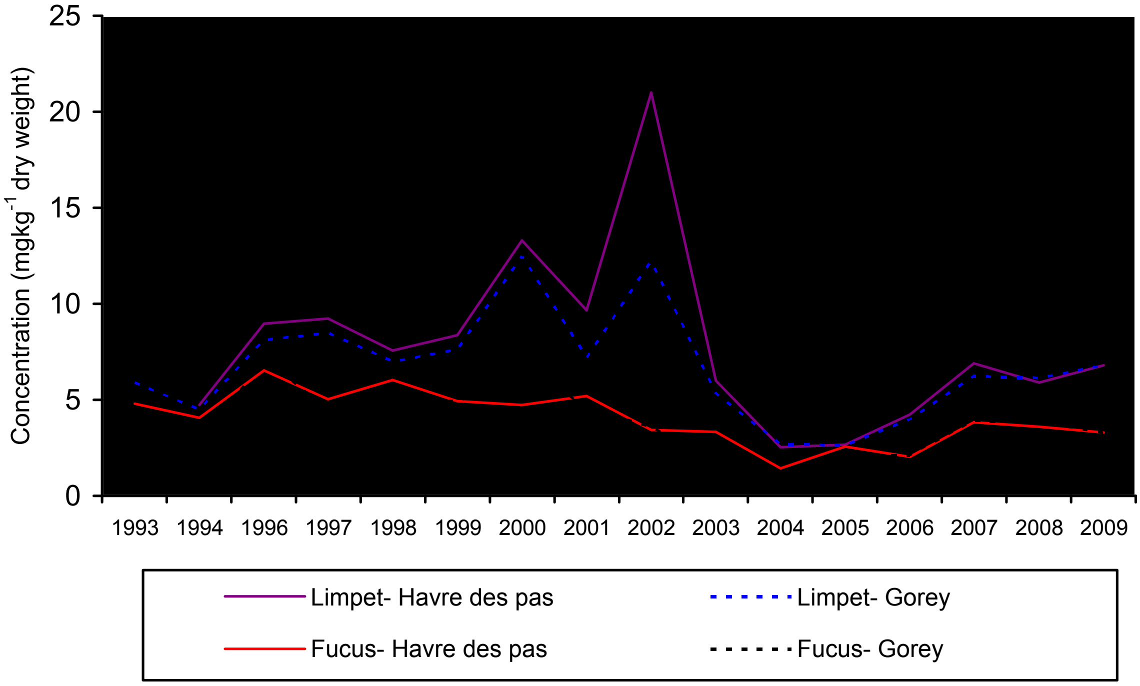


Fig. 9: Mean annual concentration (mgkg^{-1} dry weight) of copper (Cu) in the common limpet (*Patella vulgata*) and *Fucus serratus* seaweed at Havre des Pas (La Collette) and Gorey. The concentration of copper in limpets and *Fucus* was not significantly higher at La Collette than Gorey (Student paired t-test, p=0.21, *df*=48 (limpet), Student paired t-test, p=0.43, *df*=49 (*Fucus*)). Note: an extreme outlier value of 107.1 mgkg^{-1} reported for 23/04/04 for limpets at La Collette was omitted from the analysis.

Zinc

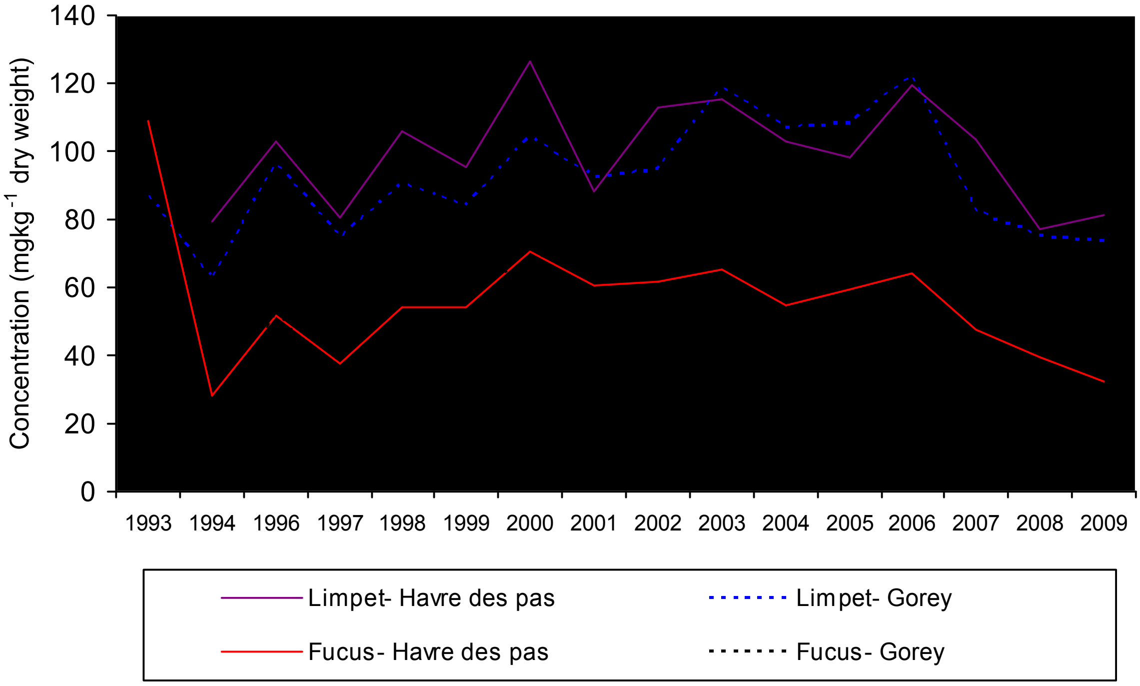


Fig. 10: Mean annual concentration (mgkg^{-1} dry weight) of copper (Cu) in the common limpet (*Patella vulgata*) and *Fucus serratus* seaweed at Havre des Pas (La Collette) and Gorey. No significant difference exists between the mean concentration of lead in limpets at La Collette and Gorey (Student paired t-test, p=0.05, df=47. The concentration of zinc in *Fucus* was significantly higher at La Collette than Gorey (Student t-test, p=0.00, df=49).

Chromium

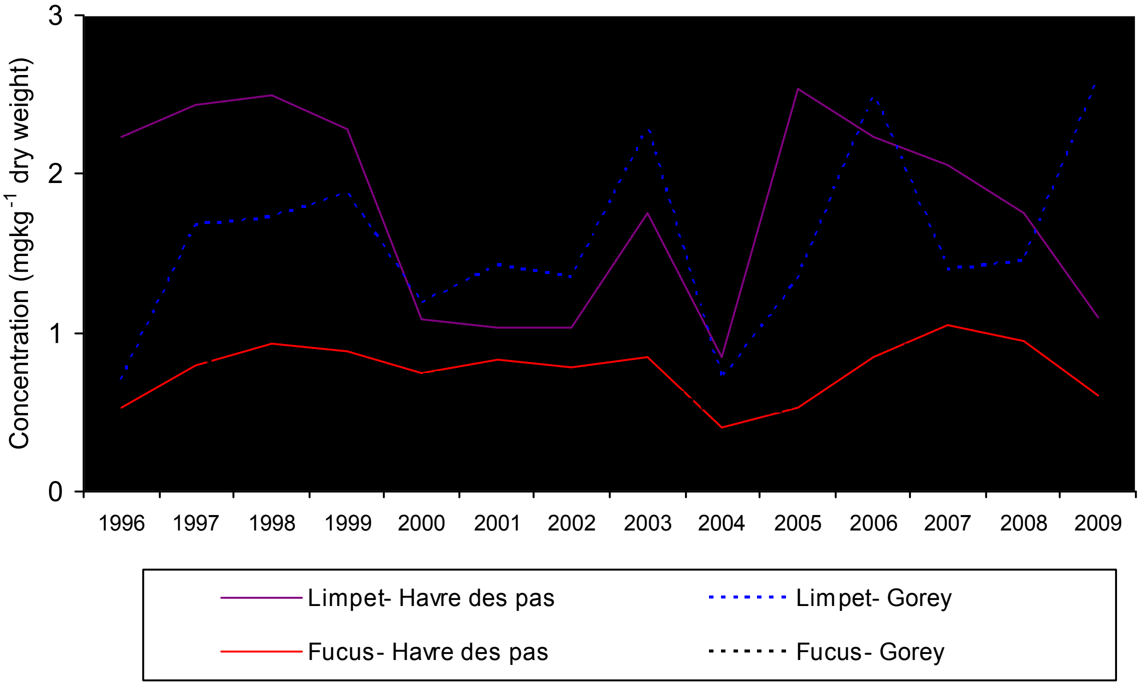


Fig. 11: Mean annual concentration (mgkg^{-1} dry weight) of chromium (Cr) in the common limpet (*Patella vulgata*) and *Fucus serratus* seaweed at Havre des Pas (La Collette) and Gorey. No significant difference exists between the mean concentration of chromium in limpets and *Fucus* at La Collette and Gorey (Wilcoxen signed rank test, Z=-1.7, p=0.08 (limpet), Student t-test, p=0.62, df=45 (*Fucus*)).

Arsenic

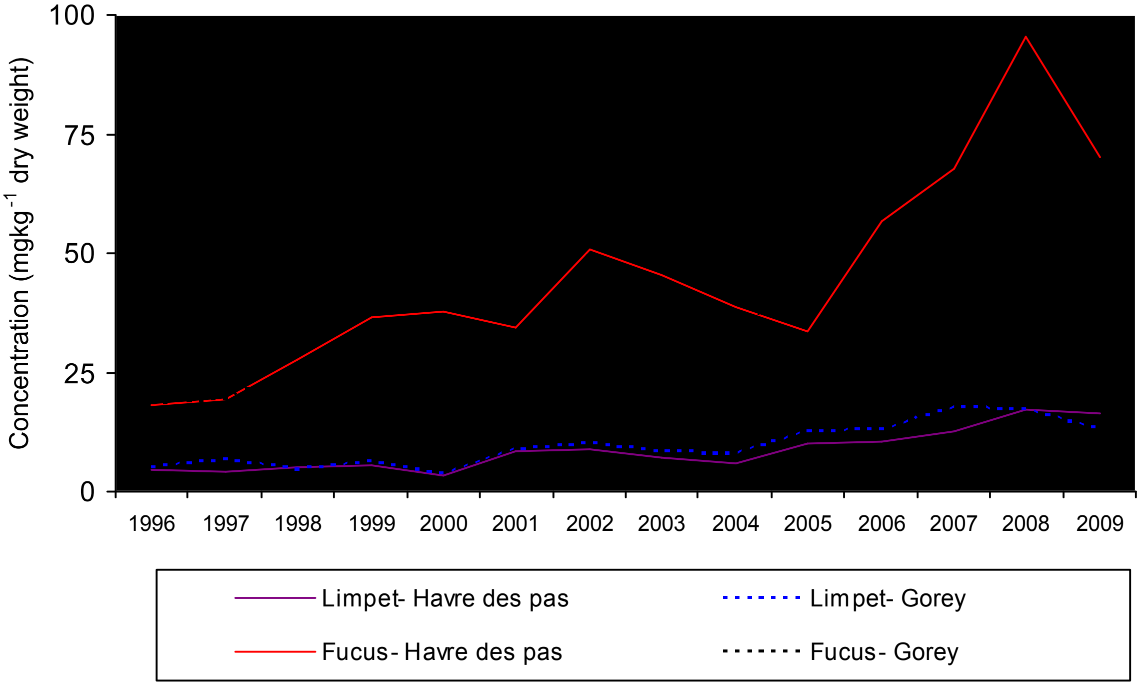


Fig. 12: Mean annual concentration (mgkg^{-1} dry weight) of arsenic (As) in the common limpet (*Patella vulgata*) and *Fucus serratus* seaweed at Havre des Pas (La Collette) and Gorey. The concentration of arsenic in limpets was significantly higher at Gorey than La Collette (Student paired t-test, p=0.00, *df*=45. No significant difference exists between the mean concentration of arsenic in *Fucus* at La Collette and Gorey (Student t-test, p=0.25, *df*=45).

Appendix 4: Comparison of annual data of the concentration of trace elements at La Collette and West of Albert. The box plots* show that the higher values reported for West of Albert were not caused by single spikes and that the higher levels at West of Albert were generally consistently higher than La Collette during the sampling period.

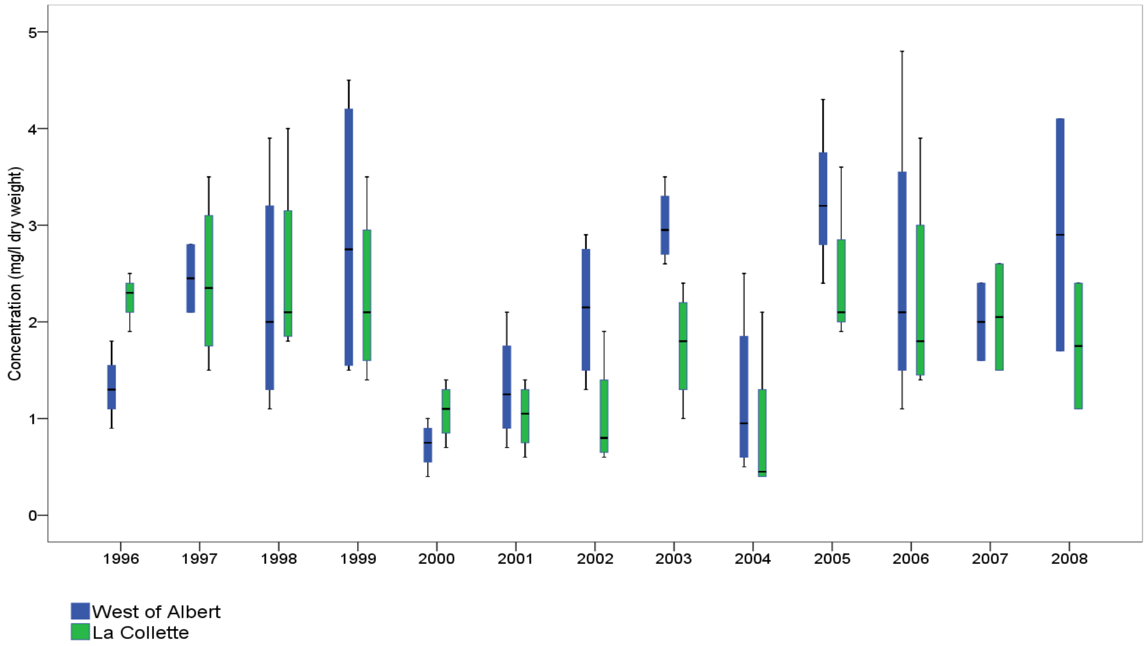


Fig. 13 Box plot of the concentration of chromium (mgl^{-1} dry weight) in limpets at West of Albert and La Collette sampling sites. The median concentration was higher at West of Albert in nine out of the thirteen years between 1996 and 2008 and for eight out of eight out of nine years between 2001 and 2009. Concentration at West of Albert was significantly higher between 1996 and 2008 (Wilcoxen signed rank test, Z=-2.5, *p*=0.01).

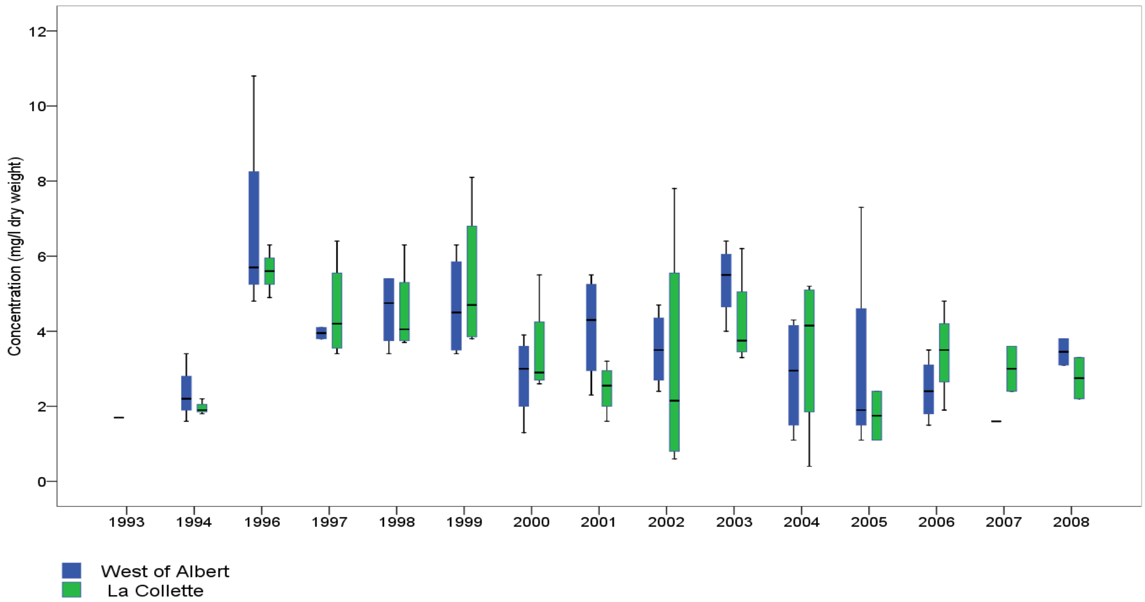


Fig. 14 Box plot of the concentration of lead (mgl^{-1} dry weight) in limpets at West of Albert and La Collette sampling sites. The median concentration was higher at West of Albert in nine out of the fourteen years between 1994 and 2008. Concentration at West of Albert was not significantly higher between 1996 and 2008 (Student paired t-test, df=19, *p*=0.90).

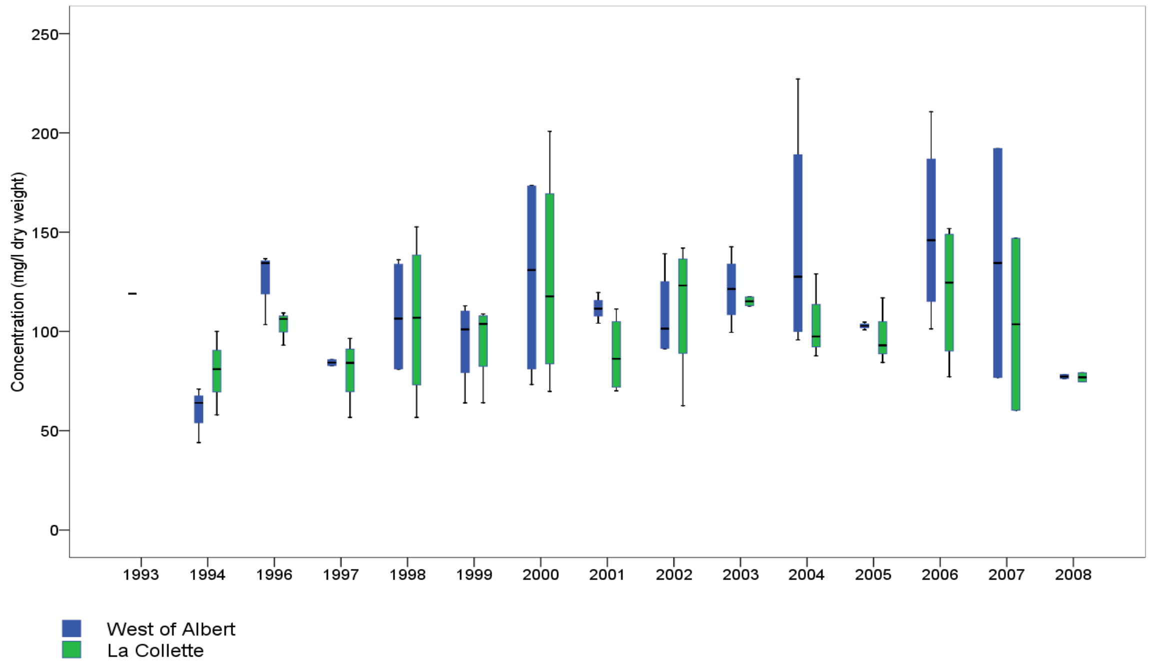


Fig. 15 Box plot of the concentration of zinc (mgl^{-1} dry weight) in limpets at West of Albert and La Collette sampling sites. The median concentration was higher at West of Albert in nine out of the fourteen years between 1994 and 2008. The concentration was particularly higher at West of Albert between 2003 and 2008. Concentration at West of Albert was not significantly higher between 1996 and 2008 (Student paired t-test, df=19, p=0.73).

* *Box plot shows the distribution of the annual data. Median value (line within the box), the 25th and 75th percentile (the lower and upper limits of the box) and values one step from the median (lower and upper lines extending from the box).*

Appendix 5: Reported trace metals levels in soft parts (mgkg^{-1}, dry weight) of the common limpet and *Fucus serratus* and *Fucus vesiculosus* in UK and Eurpean seawaters. The concentration at La Collette, Jersey (present paper) is included for comparison. Figures highlighted in red indicate higher values at La Collette.

Common limpet (*Patella vulgata*)

Location	Arsenic As	Cadmium Cd	Chromium Cr	Copper Cu	Lead Pb	Zinc Zn	Authors
EC regulation 446/2001		**5***			**7.5***		
ADRIS guide**		**15**			**50**	**500**	
Jersey- La Collette	***7.5***	***5.2***	***1.8***	***8.3***	***3.6***	***101.4***	***Present paper***
Goury, France		2.7-7.5	0.2-2.4	3.0-6.6	0.9-3.7	40-91	Miramand & Bentley, 1991
Portland, Isle of Wight		8.1				95	Leatherland & Burton, 1974
Portland, Weymouth	19-24	2.2-3.7	<1-2.9	9.7-19	1.1-2.1	63-72	Langston *et al.* 2003
Southampton water		2.7				229	" "
Irish Sea		31		7.7	32	84	Segar *et al*. 1971
North Sea		2.7-7.1		6.9-13	1.5-9.3	94-140	Dutton *et al*., 1973
Devon coast		3.9	1.4	10	13.7	101	Bryan *et al*., 1977
Looe estuary, Devon		3.3-21.5	0.5-2.6	10-27	5.1-38	83-224	Bryan & Hummerstone, 1977
SW England		13.2-17.2		42.3-45.9		240-246	Klumpp & Peterson, 1979
Norway		2-22	7-17	12-30		127-238	Lande, 1977
Fucus serratus.							
Jersey- La Collette	***41.3***	***1.0***	***0.8***	***4.1***	***2.7***	***55.5***	***Present paper***
Goury, France		0.5-1.9	0.1-0.8	0.8-2.0	0.2-2.0	32-100	Miramand & Bentley, 1991
Dorset						99	Leatherland & Burton, 1974
Irish Sea		1.1-1.4		3.2-10.1	2.1-4.0	80-171	Preston *et al.* 1972
Fucus vesiculosus							
Looe estuary, Devon		0.9-2.4	0.6-3.5	3.5-33		56-340	Bryan & Hummerstone, 1977
Tamar Estuary		1.8-9.0	1.1-10	20-107	5.9-109	138-1330	Bryan & Uysal, 1978
Bristol Channel		3.8-19.5		3.8-14.3		88-262	Fuge & James, 1974
Menai Straights		1.8-2.1	3.8-4.5	7.4-10	2.3-3.2	98-138	Foster, 1976
Baltic sea		4.7-17.2	0.11-1.44	2.2-8.0	2.0-11.7	181-877	Söderlung *et al.* 1988

* converted to dry weight by assuming a wet: dry ratio of 5.
** ADRIS (Scottish coastal water classification scheme) guide relates to unspecified shellfish.
*** Commission Regulation (EC) No 446/2001 of 5 March 2001 establishing the standard import values for food products.