Fisheries Research Services Contract Report No 10/05

CONTINUED MONITORING OF POLYCYCLIC AROMATIC HYDROCARBON (PAH) CONTAMINATION IN LOCH LEVEN

FSA (Scotland) Project Code: SO2021

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June 2005

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CUSTOMER: FOOD STANDARDS AGENCY (SCOTLAND)
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SUMMARY

During the period April 1999 to August 2001, the Fisheries Research Services Marine Laboratory (FRS ML), on behalf of the Food Standards Agency (Scotland) (FSA(S)), carried out investigations into the concentration and composition of the polycyclic aromatic hydrocarbon (PAH) in farmed blue mussels (*Mytilus edulis*) from the Kinlochleven shellfish farm in Loch Leven and from a reference shellfish farm in Loch Etive. Further investigations have been carried out over the winter months, November to March, in 2001/2002, 2002/2003 and 2003/2004. The concentration and composition of the PAH in mussels from the Kinlochleven shellfish farm in Loch Leven and from Loch Etive has been determined during the period November 2004 to March 2005.

A maximum total measured PAH concentration in Kinlochleven mussels (187.8 ng g^{-1} wet weight PAH) was observed in December 2004 and from Loch Etive mussels (53.8 ng g^{-1} wet weight PAH) in November 2004. The PAH concentrations were consistently higher in mussels from the Kinlochleven mussel farm over the winter monitoring period.

The five-ring PAHs continued to dominate the PAH profiles of the mussels from the Kinlochleven farm. This contrasted with the mussels from Loch Etive where the lower molecular weight (3- and 4-ring) compounds were more significant.

In no case did the PAH compound benzo[*a*]pyrene, considered to be of greatest concern in terms of human health, exceed 10 ng g^{-1} wet weight, (EC Commission Regulation 208/2005).

BACKGROUND

Investigations have been conducted by the Fisheries Research Services Marine Laboratory (FRS ML) for the Food Standards Agency (Scotland) (FSA(S)) during 1999 to 2001 into the concentrations of polycyclic aromatic hydrocarbons (PAHs) in farmed mussels from Loch Leven. The PAH concentrations were considerably greater than had been recorded from mussels sampled elsewhere around the Scottish mainland. It is very likely that the source of the contamination was an effluent discharged from the Alcan aluminium smelter at Kinlochleven.

In September 1999, the elevated concentrations of PAH in mussels from Loch Leven led the shellfish producers, based on the precautionary principle, to implement a voluntary prohibition on harvesting mussels for human consumption at both the Ballachulish and Kinlochleven shellfish farm sites in Loch Leven. In February 2001, based on total PAH determined in mussels from Kinlochleven and concentrations of three individual PAH compounds identified by the UK Committee on Toxicology of Chemicals in Food, Consumer Products and the Environment (COT), the FSA(S) relaxed the voluntary closure to allow commercial harvesting of mussels for human consumption to recommence at the Ballachulish shellfish farm in Loch Leven. In September 2001, based on equivalent data, the FSA(S) relaxed the voluntary prohibition on harvesting at the Kinlochleven shellfish farm.

Over the winter months November to March, 2001/02, 2002/03 and 2003/04 the PAH concentrations were determined in mussels from the Kinlochleven shellfish farm site and, as a reference site, a shellfish farm in Loch Etive. The FRS ML has carried out a further over winter study on behalf of the FSA(S) in mussels from the Kinlochleven shellfish farm during the period November 2004 to March 2005.

MATERIALS AND METHODS

Samples of mussels , single bulk sample (~ 1 kg), were obtained at monthly intervals over the period November 2004 to March 2005 from the same location on each occasion Kinlochleven shellfish farm and from Loch Etive from November 2004 to February 2005. Locations of the various shellfish farms and procedures for transportation, sample preparation and determination of PAH concentration and composition have been described previously (McIntosh *et al*., 2004). The determination of PAH in biota is accredited at FRS ML by UKAS under ISO 17025.

RESULTS AND DISCUSSION

The analytical data sets for the samples taken from the Kinlochleven mussel farm and from the reference site at Loch Etive are presented in Tables 1 and 2 respectively. Concentrations of the United States Environmental Protection Agency (US EPA) 16 priority pollutant PAH compounds are summarised in Tables 3 and 4.

The graphical representation of the total measured (2- to 6-ring parent and branched) PAH concentrations determined in mussels sampled from the Kinlochleven shellfish farm, with the equivalent data from Loch Etive mussels, covering the period November 2004 to March 2005, is shown, together with the concentrations of the US EPA 16 PAH, in Figure 1.

The total measured PAH concentration in mussels from the Kinlochleven shellfish farm sampled from November 2004 to March 2005, together with the previous three years' data, are shown, for comparison, in Figure 2a and from Loch Etive in Figure 2b.

Over the five month period presented in this report, the total PAH concentration in mussels from Kinlochleven ranged from 116.1 ng g^{-1} to 187.8 ng g^{-1} wet weight tissue compared to those from Loch Etive which ranged from 39.0 ng g^{-1} to 53.8 ng g^{-1} wet weight. The highest concentrations were seen in the December sample from Kinlochleven and in the November sample from the Loch Etive. It is interesting to note that the PAH concentrations determined in mussels at both shellfish farm sites over the winter period 2004/05 did not exhibit a pronounced seasonal variation seen in previous over winter surveys. Seasonal variation has been noted previously (Fig. 2) when, during maturation, over the period December to March, higher concentrations of PAH are associated with increased lipid deposition. There is a loss of lipid rich tissue post spawning with a consequential reduction in PAH tissue concentration.

The PAH concentrations (mean 151.8 ng g^{-1} wet weight; SD 25.7) determined in mussels over the 2004/05 monitoring period were significantly lower ($p \leq 0.05$) than the equivalent samples (mean 234.9 ng g^{-1} wet weight; SD 65.4) from the 2003/04 monitoring period. Regression analysis, of the monthly total 2- to 6-ring PAH concentrations, shows a significant reduction ($p \leq 0.05$) in mean total measured PAH concentrations in mussels from both Kinlochleven (Fig. 3a) and Loch Etive (Fig. 3b) over the four winter monitoring periods.

Over the past three winter monitoring periods, the total measured (2- to 6-ring) PAH profile in mussels from Kinlochleven has been dominated by the 5-ring compounds (Fig. 4a). The same pattern is again seen for mussels sampled over the 2004/05 winter period. The decrease in total PAH concentration from 2001 to 2005 is reflected in decreases in the concentrations of 4-ring (228), 5- and 6-ring compounds. In contrast, the PAH profile for mussels from Loch Etive shows a greater contribution from the lower molecular weight (3- and 4-ring) PAH compounds (Fig. 4b), a pattern which is repeated for the mussels sampled from Loch Etive over the 2004/05 winter period.

The mean PAH percentage composition profile in mussels from Kinlochleven, over the winter monitoring period November 2004 to March 2005 (Fig. 5a) is broadly similar to the previous over winter monitoring studies and dominated by the 5-ring compounds (Fig. 5b). The 5-ring compounds did not dominate the PAH profiles of the mussels from Loch Etive (Fig. 5c) where the total percentage contribution from the 4-ring PAH compounds was more pronounced.

The PAH percentage composition of the 5-ring compounds in mussels from both Kinlochleven (Fig. 6a) and Loch Etive (Fig. 6b) was broadly similar and dominated by the combined benzo[*b*][*k*][*j*]fluoranthene parent compounds and has not changed significantly over the past four years at either Kinlochleven (Fig. 7a) or Loch Etive (Fig. 7b).

The ratio of 2- to 6-ring PAH (excluding the US EPA 16) to the US EPA 16 PAH in mussels from Kinlochleven ranged from 0.88 to 1.6 and in mussels from Loch Etive from 0.32 to 0.41 (Fig. 8). The [US EPA 16 PAH]/[Total PAH – US EPA 16 PAH] ratio is significantly greater ($p \leq 0.05$) in the mussels from Kinlochleven over the winter months period November 2004 to March 2005 (Loch Etive, February 2005). This is the result of the greater concentration of 5-ring parent compounds present in mussels from Kinlochleven.

The interim pragmatic guideline limit, for use in emergencies, of 15 ng g^{-1} fresh weight, adopted by the UK Food Standards Agency, advised by the UK Committee on Toxicology of Chemicals in Food, Consumer Products and the Environment (COT), for the concentrations of selected PAH compounds and applying to three compounds individually: benz[*a*]anthracene, benzo[*a*]pyrene and dibenz[*a,h*]anthracene, has been used by the FSA(S) in relation to their advice on the PAH concentrations in mussels from Loch Leven.

In February 2005, an EC Commission Regulation (EC 208/2005) set a maximum concentration of 10 ng g^{-1} wet weight for benzo[*a*]pyrene to be used as a marker for the occurrence and effect of carcinogenic PAH[1] in food. Concentrations above this limit would render the product unsuitable for human consumption. The concentrations of benzo[*a*]pyrene for all samples of mussels from Kinlochleven and Loch Etive over the winter months November 2004 to March 2005 (Fig. 9) were below the 10 ng g^{-1} fresh weight limit. The benzo[*a*]pyrene concentrations in mussels from Kinlochleven over the period November

[1]According to the EU Scientific Committee on Food, benzo[*a*]pyrene can be used as a marker for the occurrence and effect of carcinogenic PAH in food, including also benz[*a*]anthracene, benzo[*b*]fluoranthene, benzo[*j*]fluoranthene, benzo[*k*]fluoranthene, benzo[*g,h,i*]perylene, chrysene, cyclopenta[*c,d*]pyrene, dibenz[*a,h*]anthracene, dibenzo[*a,e*]pyrene, dibenzo[*a,h*]pyrene, dibenzo[*a,i*]pyrene, dibenzo[*a,l*]pyrene, indeno[1,2,3-*cd*]pyrene and 5-methylchrysene.

2004 to March 2005 are shown in context (Fig. 10) of the benzo[*a*]pyrene concentrations determined in previous studies.

CONCLUSIONS

The total measured (2- to 6-ring parent and branched) PAH concentrations determined in mussels from Kinlochleven over the winter monitoring period November 2004 to March 2005 were lower, except in December 2004 than the equivalent concentrations determined over the period November 2003 to March 2004. Furthermore, the mean PAH concentration determined in mussels over the 2004/05 monitoring period was significantly lower ($p \leq 0.05$) then the equivalent concentration from the 2003/04 monitoring period. The total measured PAH concentrations have decreased consistently since 2001/02.

There was no pronounced seasonal variation in total measured PAH concentration observed over this winter monitoring period.

Benzo[*a*]pyrene concentrations determined in mussels from Kinlochleven over the monitoring period November 2004 to March 2005 were less than 10 ng g-1 wet weight and therefore within the Commission Regulation (EC 208/2005) limit for benzo[*a*]pyrene in bivalve molluscs. The benzo[*a*]pyrene concentrations in mussels from Kinlochleven remain significantly greater than the benzo[*a*]pyrene concentrations in mussels from Loch Etive.

REFERENCES

McIntosh, A.D., Moffat, C.F., Packer, G. and Webster, L. 2004. Polycyclic aromatic hydrocarbon (PAH) concentration and composition determined in farmed blue mussels (*Mytilus edulis*) in a sea loch pre- and post-closure of an aluminium smelter. *J. Environ. Monit.*, **6**, 209-218.

Commission Regulation (EC) No 208/2005 of 4 February 2005 amending Regulation (EC) No 466/2001 as regards polycyclic aromatic hydrocarbons setting maximum concentrations for certain contaminants in foodstuffs.

Table 1

Total measured [PAH] (µg kg^{-1} wet weight tissue) in mussels from Kinlochleven shellfish farm over period November 2004 to March 2005

	17 November 2004	8 December 2004	26 January 2005	23 February 2005	29 March 2005
Naphthalene	TR	TR	TR	TR	TR
2-Methyl Naphthalene	TR	TR	TR	ND	TR
1-Methyl Naphthalene	TR	TR	TR	ND	TR
C2 Naphthalenes	0.2	0.3	0.6	0.3	0.4
C3 Naphthalenes	0.3	0.5	0.7	0.3	0.4
C4 Naphthalenes	0.3	0.6	0.5	0.2	0.3
TOTAL Naphthalenes	0.8	1.4	1.8	0.8	1.1
Acenaphthylene (152)	ND	ND	TR	ND	TR
Acenaphthene (154)	TR	TR	TR	ND	ND
Fluorene (166)	0.2	0.2	0.2	TR	TR
subtotal	0.2	0.2	0.2	TR	TR
Phenanthrene (178)	1.4	1.1	1.4	0.9	0.8
Anthracene (178)	0.2	0.2	0.2	TR	ND
C1 178	1.8	2.2	2.9	1.8	1.5
C2 178	2.5	3.1	4.3	2.6	1.9
C3 178	3.2	3.8	4.4	2.4	1.5
TOTAL 178	9.1	10.4	13.2	7.7	5.7
Dibenzothiophene	TR	TR	TR	TR	ND
C1 Dibenzothiophenes*	0.2	0.3	0.3	0.2	0.2
C2 Dibenzothiophenes*	0.9	1.2	1.5	0.9	0.5
C3 Dibenzothiophenes*	1.2	1.5	1.9	0.9	0.4
TOTAL DBTs	2.3	3.0	3.7	2.0	1.1
Fluoranthene (202)	3.2	2.6	3.4	2.9	1.8
Pyrene (202)	3.5	3.4	3.4	3.5	1.8
C1 202	6.1	7.0	6.5	5.8	4.2
C2 202	3.7	4.7	4.4	4.4	2.8
C3 202*	1.9	2.5	1.9	2.1	1.6
TOTAL 202	18.4	20.2	19.6	18.7	12.2
Benzo[*c*]phenanthrene (228)	1.0	1.3	1.1	1.0	0.7
Benz[*a*]anthracene (228)	2.5	2.5	1.4	1.6	2.1
Chrysene/Triphenylene (228)	5.4	6.0	5.6	6.0	3.7
Benz[*b*]anthracene (228)*	0.2	0.2	TR	TR	TR
C1 228	8.3	9.7	6.7	8.1	5.7
C2 228	3.4	4.2	4.4	5.7	2.7
TOTAL 228	20.8	23.9	19.2	22.4	14.9
Benzofluoranthenes (252)	44.5	53.7	39.0	47.0	31.4
Benzo[*e*]pyrene (252)	21.7	27.2	24.0	24.8	18.9
Benzo[*a*]pyrene (252)	6.5	7.8	4.9	6.8	4.8
Perylene (252)	2.2	2.7	2.1	2.4	1.3
C1 252	12.5	15.7	8.8	10.8	10.2
C2 252*	1.5	1.8	0.9	1.1	1.4
TOTAL 252	88.9	108.9	79.7	92.9	68.0
Dibenz[*a,h*]anthracene (278)	1.5	2.1	0.4	0.6	0.9
5-ring total	90.4	111.0	80.1	93.5	68.9
Indenopyrene (276)	5.9	6.7	2.0	2.8	4.2
Benzoperylene (276)	7.6	9.8	4.5	5.3	6.8
C1 276*	1.0	1.2	0.4	0.5	0.7
C2 276*	ND	ND	0.2	0.2	0.5
TOTAL 276	14.5	17.7	7.1	8.8	12.2
Total measured PAH	156.5	187.8	144.9	153.9	116.1

* not included in UKAS accreditation

ND = not detected (<0.04 µg kg^{-1} wet weight); TR = trace (0.04 - 0.14 µg kg^{-1} wet weight)

1.

Table 2

Total measured [PAH] (µg kg^{-1} wet weight tissue) in mussels from a Loch Etive shellfish farm over period November 2004 to February 2005

	17 November 2004	08 December 2004	17 January 2005	14 February 2005	March 2005
Naphthalene	0.2	TR	TR	0.2	
2-Methyl Naphthalene	0.2	TR	TR	TR	
1-Methyl Naphthalene	TR	TR	TR	TR	Loch Etive was not
C2 Naphthalenes	0.8	0.3	1.0	0.5	sampled in March 2005
C3 Naphthalenes	1.4	0.5	1.5	0.9	
C4 Naphthalenes	1.7	0.8	1.4	1.0	
TOTAL Naphthalenes	4.3	1.6	3.9	2.6	
Acenaphthylene (152)	ND	ND	ND	ND	
Acenaphthene (154)	TR	ND	TR	ND	
Fluorene (166)	TR	TR	TR	TR	
subtotal	TR	TR	TR	TR	
Phenanthrene (178)	1.2	0.8	1.1	1.0	
Anthracene (178)	TR	TR	TR	TR	
C1 178	4.0	2.2	3.7	3.3	
C2 178	6.2	3.6	4.8	5.1	
C3 178	5.3	3.2	3.5	4.1	
TOTAL 178	16.7	9.8	13.1	13.5	
Dibenzothiophene	TR	TR	TR	TR	
C1 Dibenzothiophenes*	0.8	0.4	0.7	0.4	
C2 Dibenzothiophenes*	2.5	1.5	1.9	1.8	
C3 Dibenzothiophenes*	2.3	1.4	1.6	1.6	
TOTAL DBTs	5.6	3.3	4.2	3.8	
Fluoranthene (202)	2.0	1.5	1.2	1.7	
Pyrene (202)	1.6	1.3	1.1	1.4	
C1 202	3.3	2.2	1.7	2.2	
C2 202	2.1	1.7	1.6	2.2	
C3 202*	1.4	1.2	1.1	1.5	
TOTAL 202	10.4	7.9	6.7	9.0	
Benzo[*c*]phenanthrene (228)	0.3	0.3	0.2	0.3	
Benz[*a*]anthracene (228)	0.8	0.8	0.4	0.7	
Chrysene/Triphenylene (228)	1.9	1.5	1.4	2.3	
Benz[*b*]anthracene (228)*	ND	ND	ND	ND	
C1 228	2.0	1.9	1.7	2.9	
C2 228	1.6	1.6	2.2	3.1	
TOTAL 228	6.6	6.1	5.9	9.3	
Benzofluoranthenes (252)	3.9	3.7	4.6	5.7	
Benzo[*e*]pyrene (252)	2.0	1.8	2.0	2.6	
Benzo[*a*]pyrene (252)	0.3	0.3	0.6	0.7	
Perylene (252)	0.8	0.9	0.7	0.8	
C1 252	1.4	1.5	1.4	2.0	
C2 252*	0.4	0.5	0.4	0.5	
TOTAL 252	8.8	8.7	9.7	12.3	
Dibenz[*a,h*]anthracene (278)	TR	TR	ND	TR	
5-ring total	8.8	8.7	9.7	12.3	
Indenopyrene (276)	0.6	0.7	0.3	0.3	
Benzoperylene (276)	0.6	0.7	0.4	0.5	
C1 276*	0.2	0.2	TR	TR	
C2 276*	ND	ND	ND	ND	
TOTAL 276	1.4	1.6	0.7	0.8	
Total measured PAH	53.8	39.0	44.2	51.3	

* not included in UKAS accreditation

ND = not detected (<0.04 µg kg^{-1} wet weight); TR = trace (0.04 - 0.14 µg kg^{-1} wet weight)

Table 3

EPA 16 PAH concentration (µg kg^{-1} wet weight tissue) in mussels from Kinlochleven (November 2004 to March 2005 inclusive)

	Nov-04	Dec-04	Jan-05	Feb-05	Mar-05
Naphthalene	TR	TR	TR	TR	TR
Acenaphthylene (152)	ND	ND	TR	ND	TR
Acenaphthene (154)	TR	TR	TR	ND	ND
Fluorene (166)	0.2	0.2	0.2	TR	TR
Phenanthrene (178)	1.4	1.1	1.4	0.9	0.8
Anthracene (178)	0.2	0.2	0.2	TR	ND
Fluoranthene (202)	3.2	2.6	3.4	2.9	1.8
Pyrene (202)	3.5	3.4	3.4	3.5	1.8
Benz[*a*]anthracene (228)	2.5	2.5	1.4	1.6	2.1
Chrysene/Triphenylene (228)	5.4	6.0	5.6	6.0	3.7
Benzofluoranthenes (252) [(1)]	44.5	53.7	39.0	47.0	31.4
Benzo[*a*]pyrene (252)	6.5	7.8	4.9	6.8	4.8
Indenopyrene (276)	5.9	6.7	2.0	2.8	4.2
Benzoperylene (276)	7.6	9.8	4.5	5.3	6.8
Dibenz[*a,h*]anthracene (278)	1.5	2.1	0.4	0.6	0.9
Total EPA 16 PAH (ng g^{-1} wet weight)	82.4	96.1	66.4	77.4	58.3

Table 4

EPA 16 PAH concentration (µg kg^{-1} wet weight tissue) in mussels from Loch Etive (November 2004 to February 2005 inclusive)

	Nov-04	Dec-04	Jan-05	Feb-05
Naphthalene	0.2	TR	TR	0.2
Acenaphthylene (152)	ND	ND	ND	ND
Acenaphthene (154)	TR	ND	TR	ND
Fluorene (166)	TR	TR	TR	TR
Phenanthrene (178)	1.2	0.8	1.1	1.0
Anthracene (178)	TR	TR	TR	TR
Fluoranthene (202)	2.0	1.5	1.2	1.7
Pyrene (202)	1.6	1.3	1.1	1.4
Benz[*a*]anthracene (228)	0.8	0.8	0.4	0.7
Chrysene/Triphenylene (228)	1.9	1.5	1.4	2.3
Benzofluoranthenes (252) [(1)]	3.9	3.7	4.6	5.7
Benzo[*a*]pyrene (252)	0.3	0.3	0.6	0.7
Indenopyrene (276)	0.6	0.7	0.3	0.3
Benzoperylene (276)	0.6	0.7	0.4	0.5
Dibenz[*a,h*]anthracene (278)	TR	TR	ND	TR
Total EPA 16 PAH (ng g^{-1} wet weight)	13.1	11.3	11.1	14.5

ND = not detected (<0.04 µg kg^{-1})
TR = trace (0.04 - 0.14 µg kg^{-1})

[(1)] Benzofluoranthenes - combined benzo[*b*], benzo[*k*] and benzo[*j*]fluoranthenes

FIGURE LEGENDS

1. Variation with time in a) the total measured polycyclic aromatic hydrocarbons (PAH) (ng g^{-1} wet weight tissue) and b) total measured USEPA 16 PAH determined in blue mussels (*Mytilus edulis*) from the Kinlochleven shellfish farm and a reference shellfish farm in Loch Etive over the winter months November 2004 to March 2005.

2. Variation with time in total measured PAH in mussels from a) Kinlochleven and b) Loch Etive shellfish farm over the winter months monitoring period November 2004 to March 2005 and a comparison with the total measured PAH in mussels from the previous winter monitoring periods November 2001 to March 2004.

3. Variation with time in total measured PAH in mussels from a) Kinlochleven and b) Loch Etive over the winter months November 2001 to March 2005.

4. Variation with time in total measured PAH groups in mussels from a) Kinlochleven and b) Loch Etive shellfish farm over four winter months monitoring periods.

5. Variation with time in mean PAH percentage composition of the 2- to 6-ring compounds in mussels from a) Kinlochleven and Loch Etive shellfish farm over the winter months November 2004 to March 2005 (Loch Etive, February 2005), from b) Kinlochleven and c) Loch Etive over four winter months monitoring periods.

6. Variation with time in PAH percentage composition of the five-ring compounds in mussels from a) Kinlochleven and b) Loch Etive shellfish farm over the winter months period November 2004 to March 2005 (Loch Etive, February 2005).

7. Variation with time in the mean 5-ring percentage composition determined in mussels from a) Kinlochleven and b) Loch Etive over four winter months monitoring periods.

8. Variation in the ratio of [USEPA 16 PAH]/[Total PAH – USEPA 16 PAH] in mussels from Kinlochleven and Loch Etive over the winter months period November 2004 to March 2005 (Loch Etive, February 2005) with equivalent data for Kinlochleven from 2001/02.

9. Variation with time in the concentrations of benzo[*a*]pyrene in mussels from Kinlochleven and Loch Etive over the period November 2004 to March 2005 (Loch Etive, February 2005).

10. Variation with time in the concentrations of benzo[*a*]pyrene determined in mussels from the Kinlochleven shellfish farm over the period November 2004 to March 2005 with data from previous monitoring periods included for comparison.

Figure 1a

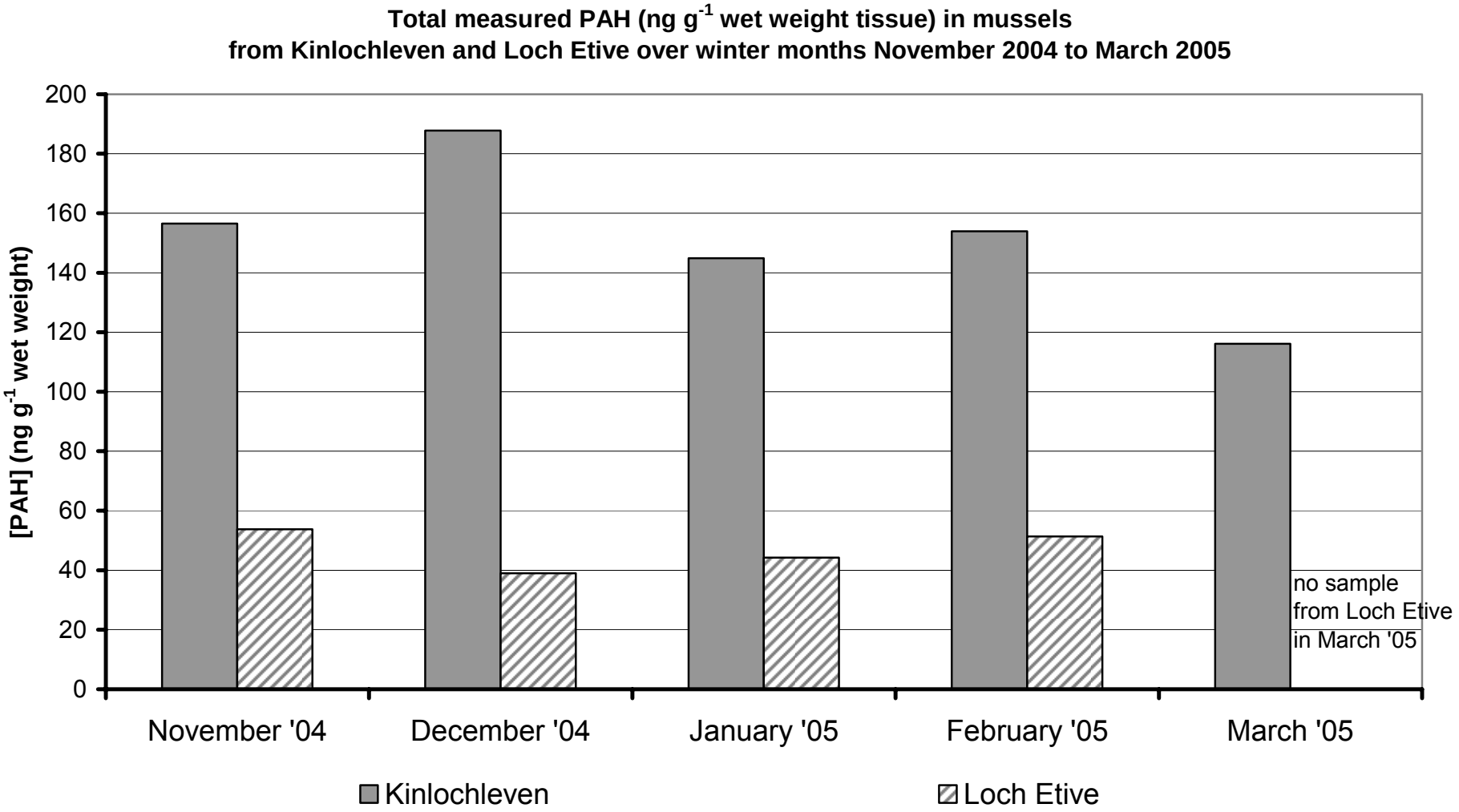

Total measured PAH (ng g-1 wet weight tissue) in mussels
from Kinlochleven and Loch Etive over winter months November 2004 to March 2005
[PAH] (ng g-1 wet weight)
200
180
160
140
120
100
80
60
40
20
0
November '04
December '04
January '05
February '05
March '05
no sample
from Loch Etive
in March '05
Kinlochleven
Loch Etive

Figure 1b

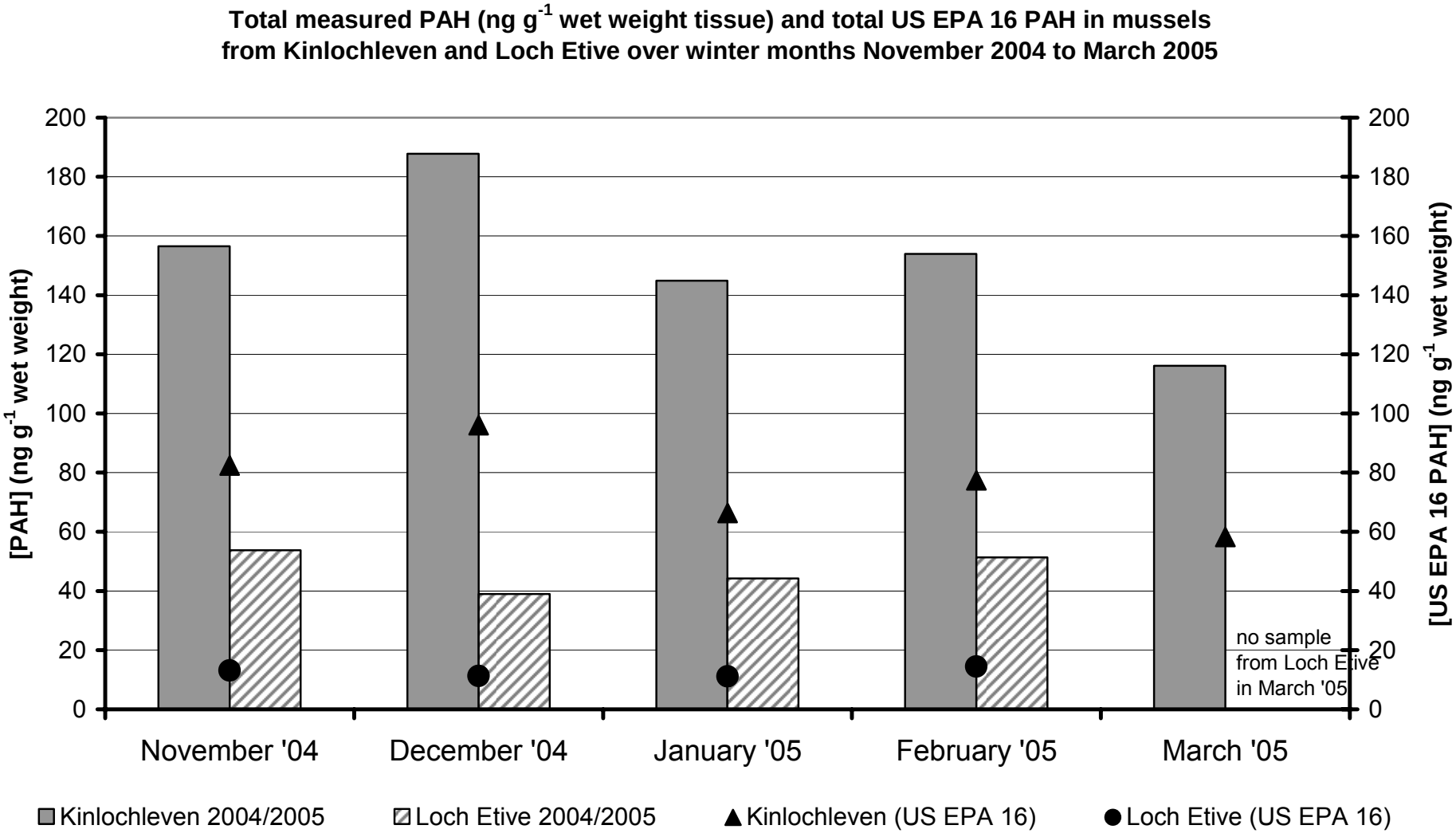

Total measured PAH (ng g-1 wet weight tissue) and total US EPA 16 PAH in mussels from Kinlochleven and Loch Etive over winter months November 2004 to March 2005
[PAH] (ng g-1 wet weight)
[US EPA 16 PAH] (ng g-1 wet weight)
0
20
40
60
80
100
120
140
160
180
200
November '04
December '04
January '05
February '05
March '05
no sample from Loch Etive in March '05
Kinlochleven 2004/2005
Loch Etive 2004/2005
Kinlochleven (US EPA 16)
Loch Etive (US EPA 16)

Figure 2a

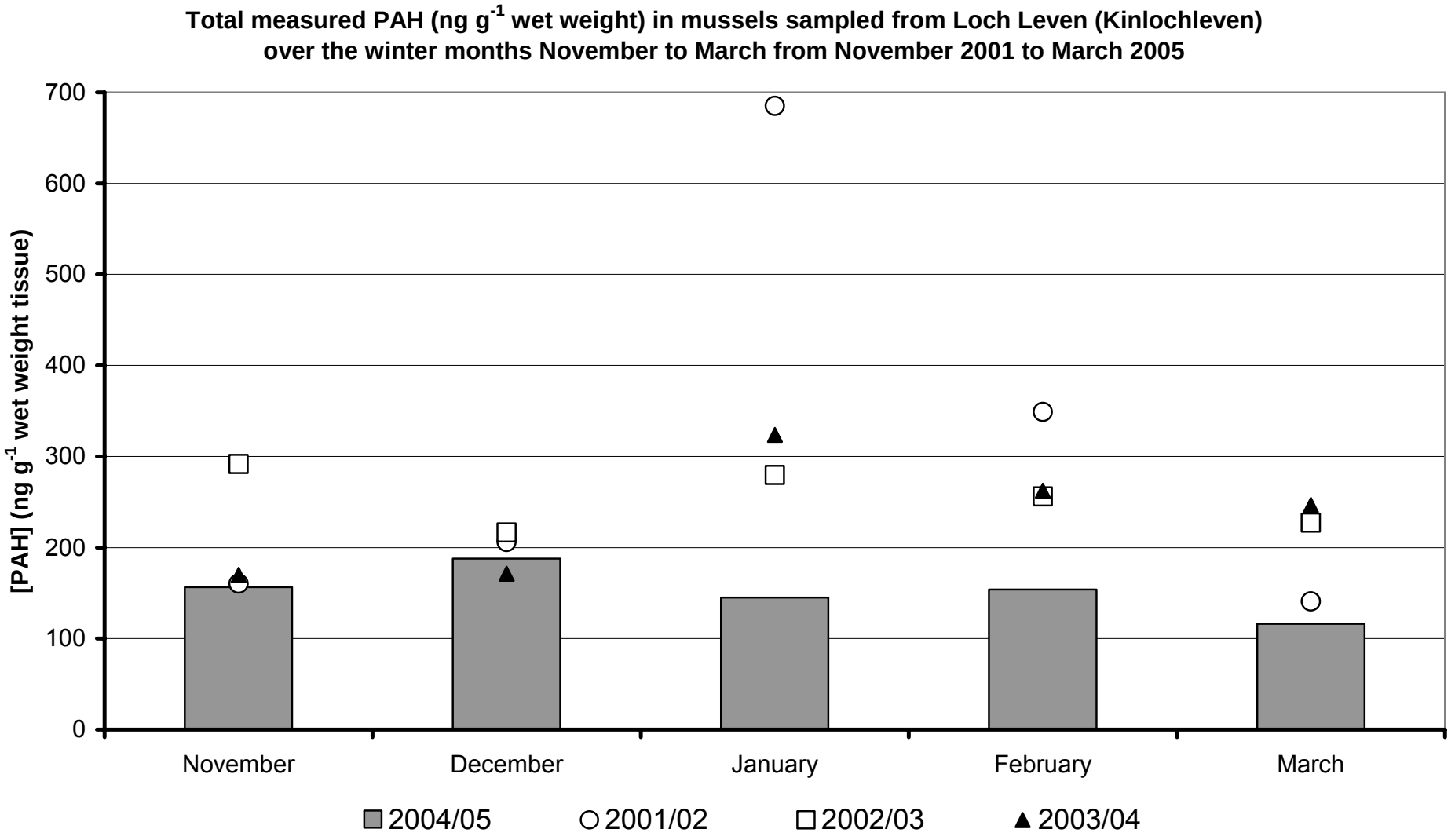

Total measured PAH (ng g-1 wet weight) in mussels sampled from Loch Leven (Kinlochleven) over the winter months November to March from November 2001 to March 2005
[PAH] (ng g-1 wet weight tissue)
700
600
500
400
300
200
100
0
November
December
January
February
March
2004/05
2001/02
2002/03
2003/04

Figure 2b

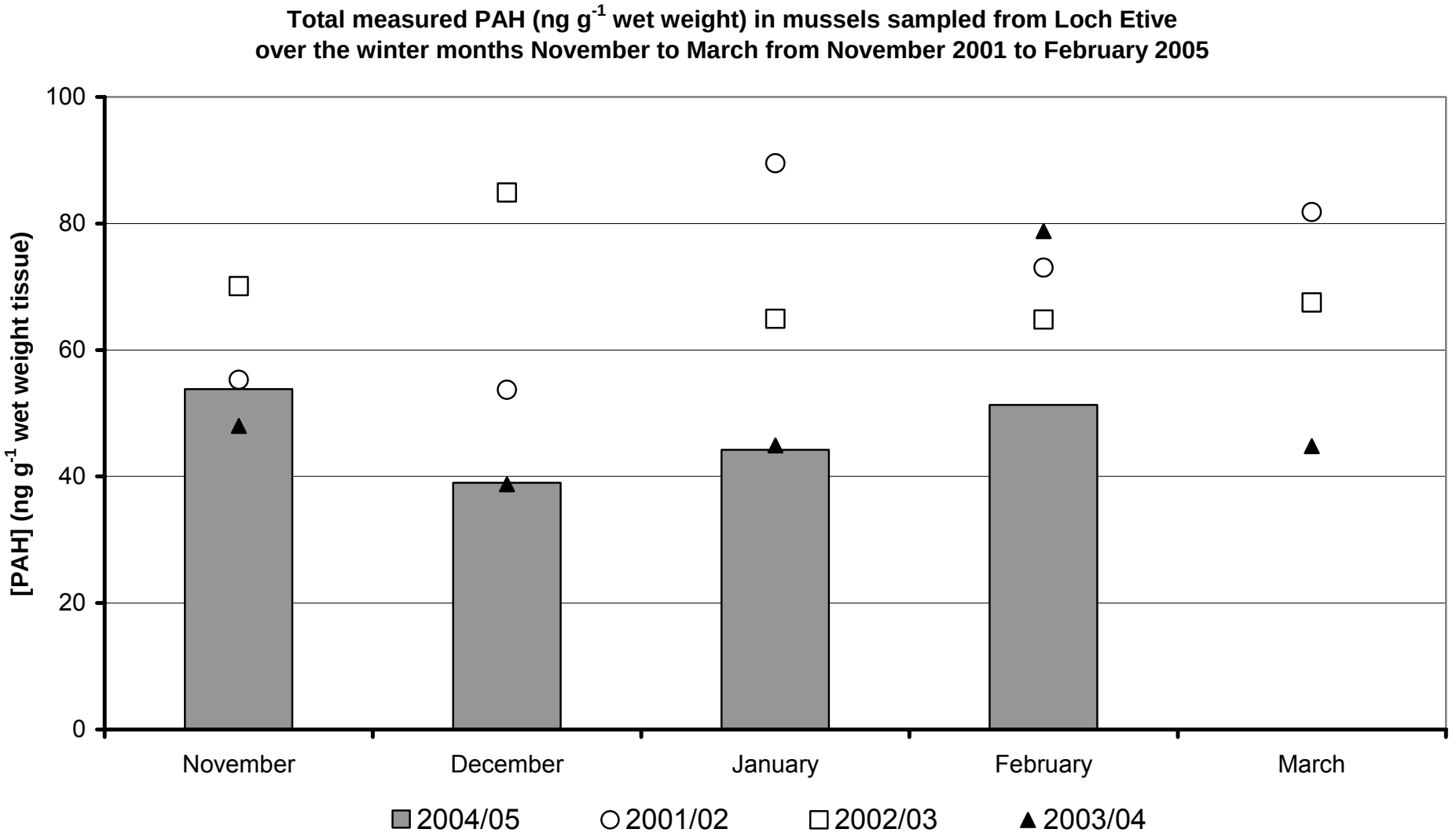

Total measured PAH (ng g-1 wet weight) in mussels sampled from Loch Etive
over the winter months November to March from November 2001 to February 2005
[PAH] (ng g-1 wet weight tissue)
100
80
60
40
20
0
November
December
January
February
March
2004/05
2001/02
2002/03
2003/04

Figure 3a

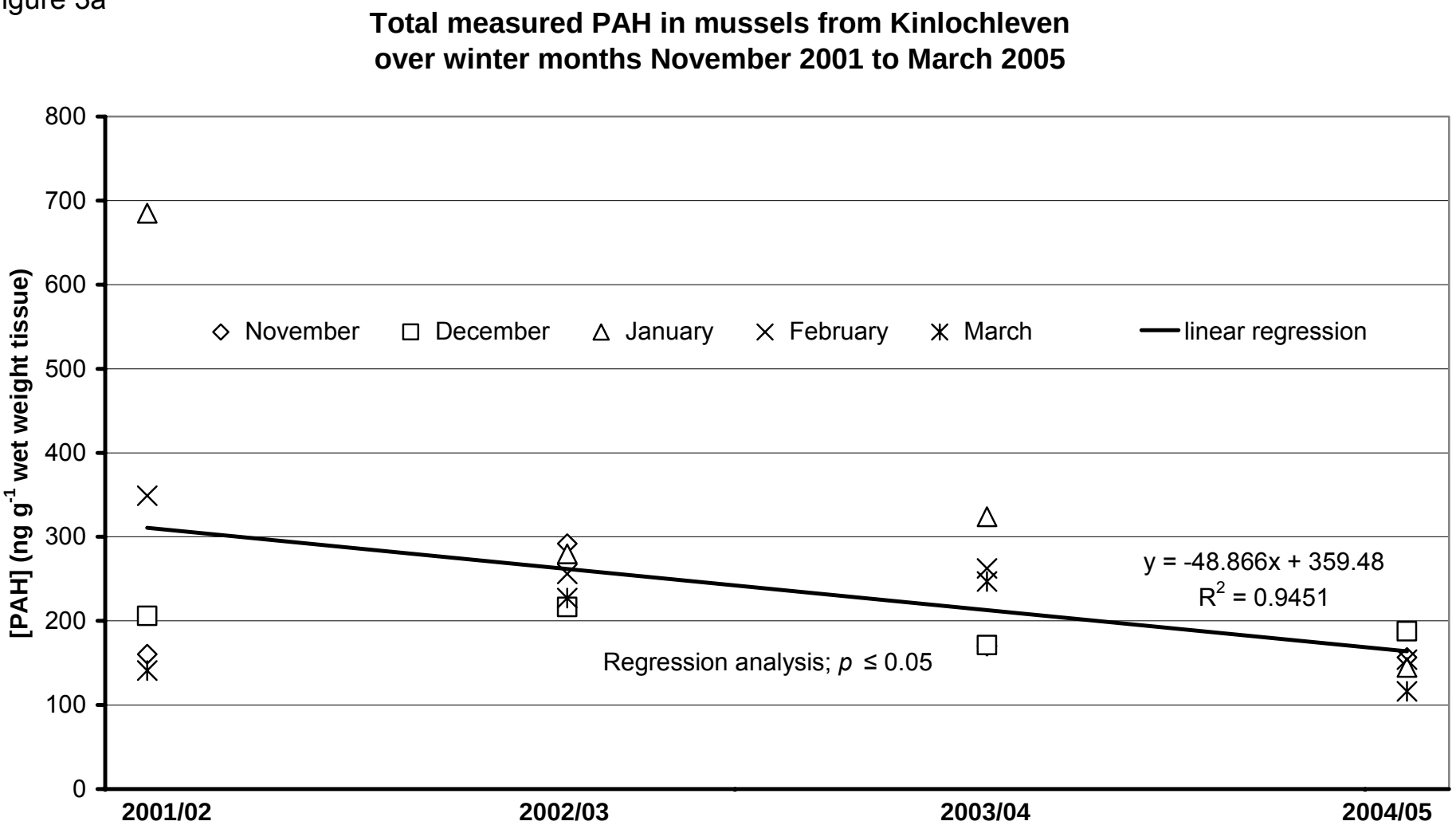

Total measured PAH in mussels from Kinlochleven over winter months November 2001 to March 2005
[PAH] (ng g-1 wet weight tissue)
800
700
600
500
400
300
200
100
0
November
December
January
February
March
linear regression
y = -48.866x + 359.48
R2 = 0.9451
Regression analysis; p ≤ 0.05
2001/02
2002/03
2003/04
2004/05

Figure 3b

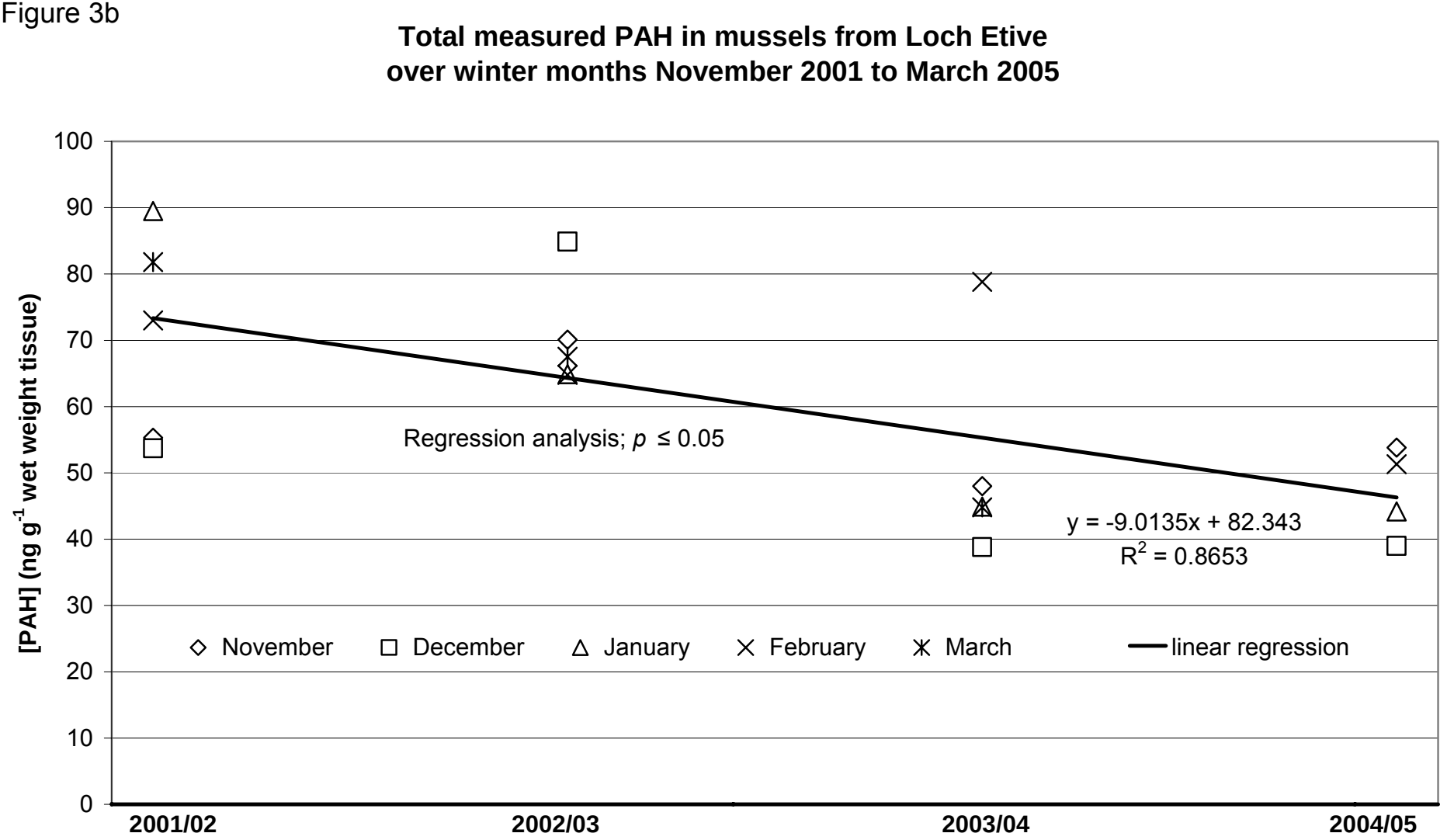
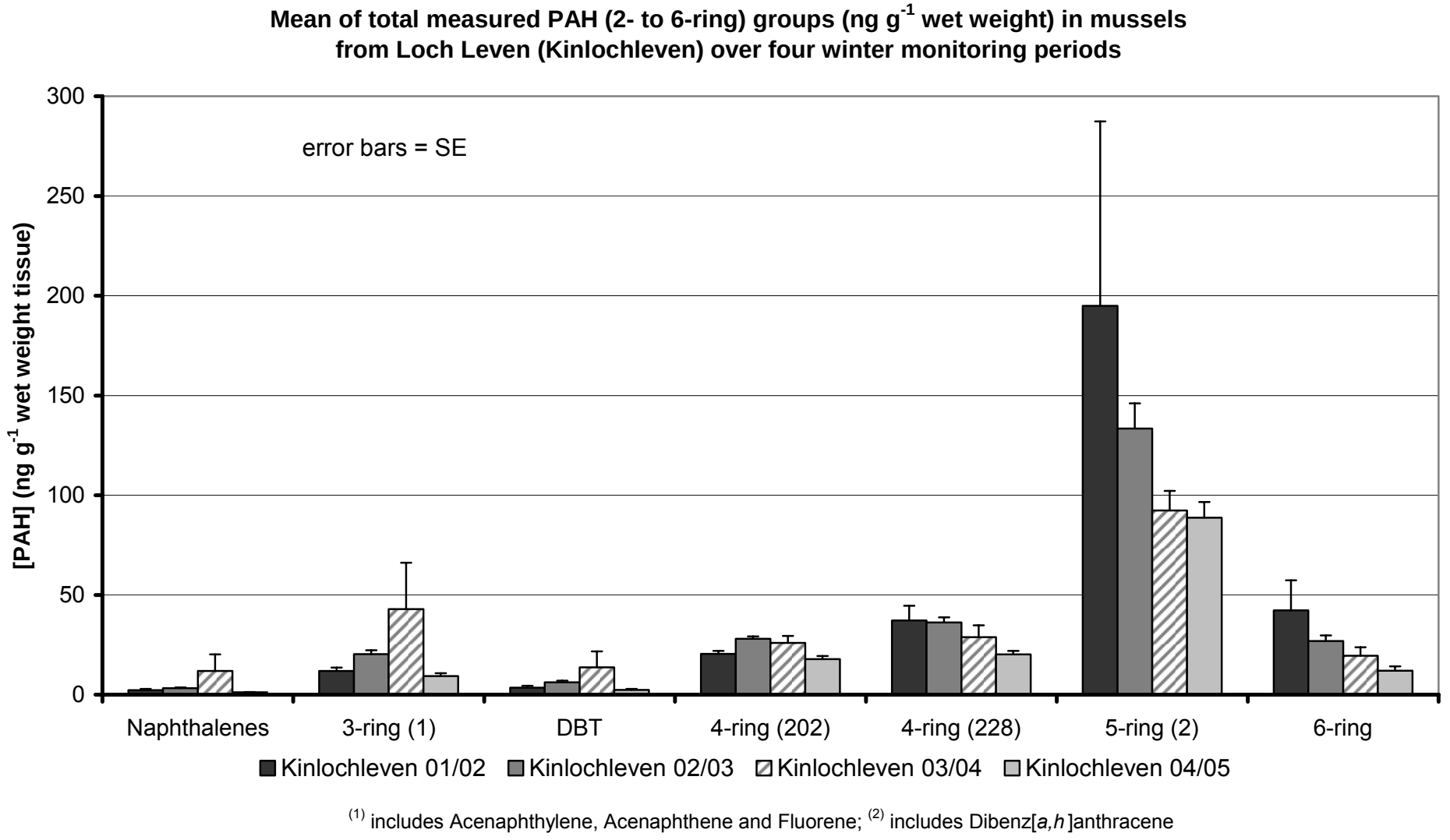
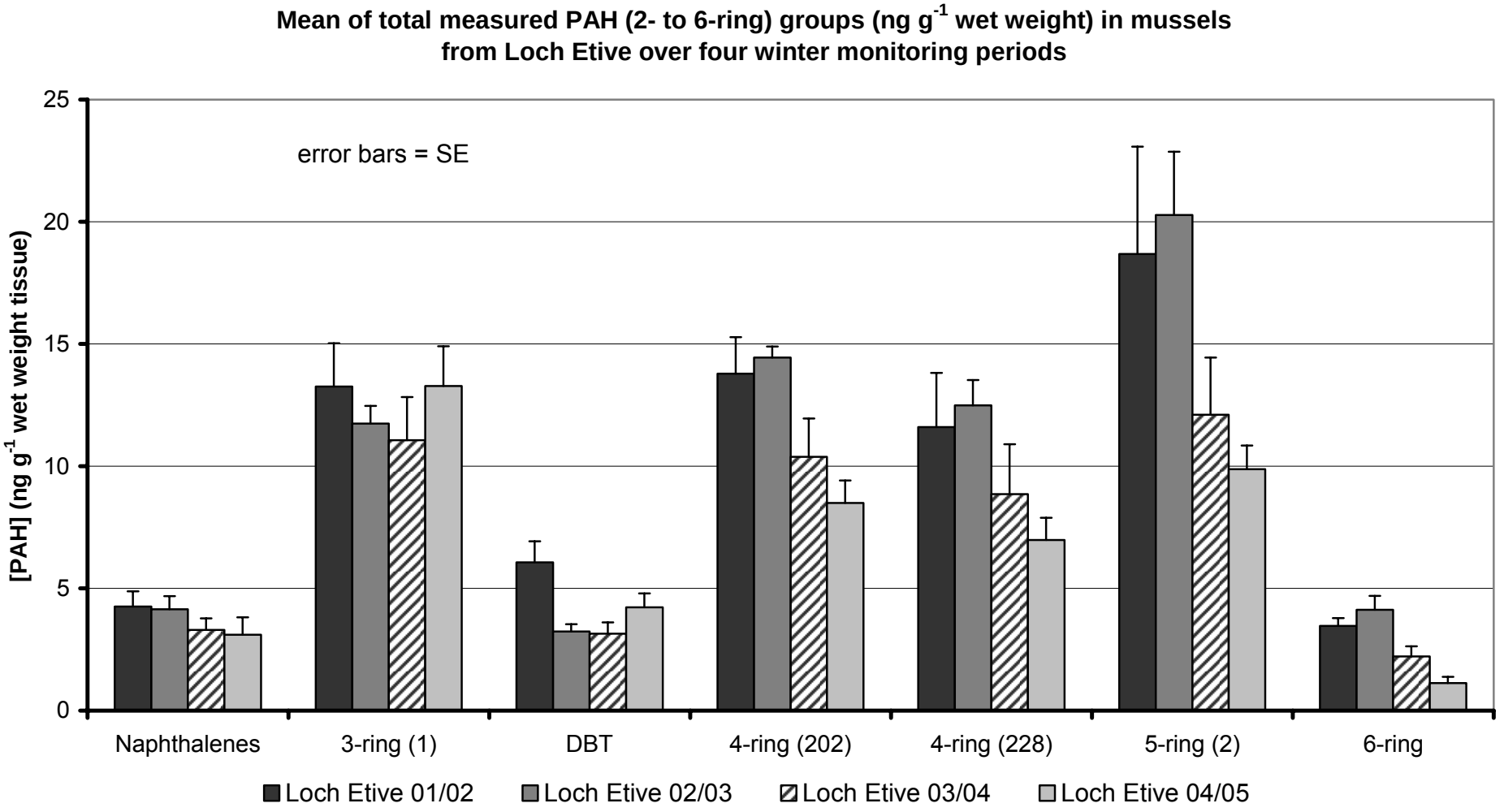

Total measured PAH in mussels from Loch Etive
over winter months November 2001 to March 2005
[PAH] (ng g-1 wet weight tissue)
100
90
80
70
60
50
40
30
20
10
0
2001/02
2002/03
2003/04
2004/05
Regression analysis; p ≤ 0.05
y = -9.0135x + 82.343
R2 = 0.8653
November
December
January
February
March
linear regression

Figure 4a



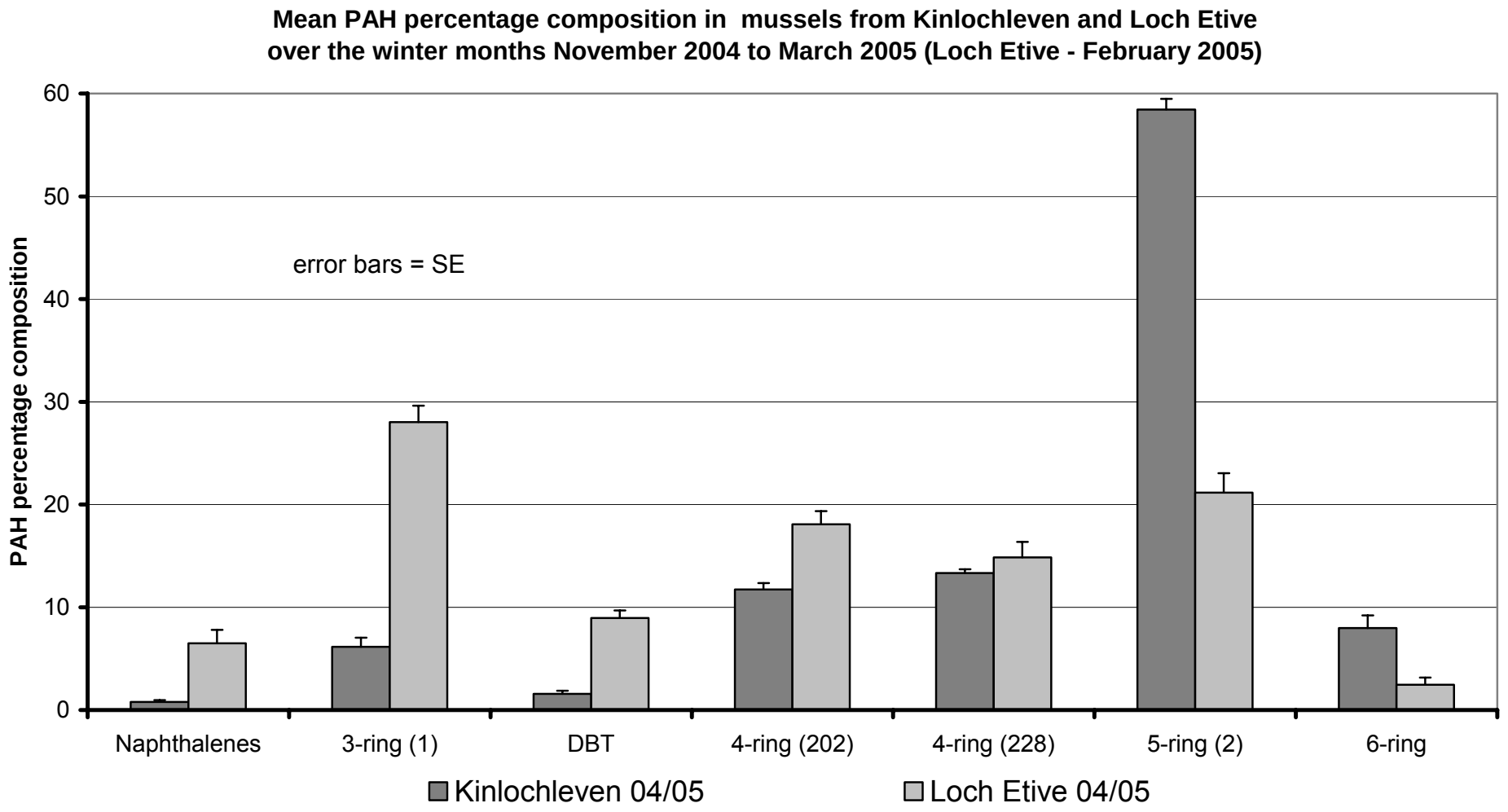
(1) includes Acenaphthylene, Acenaphthene and Fluorene; (2) includes Dibenz[*a,h*]anthracene

Figure 4b



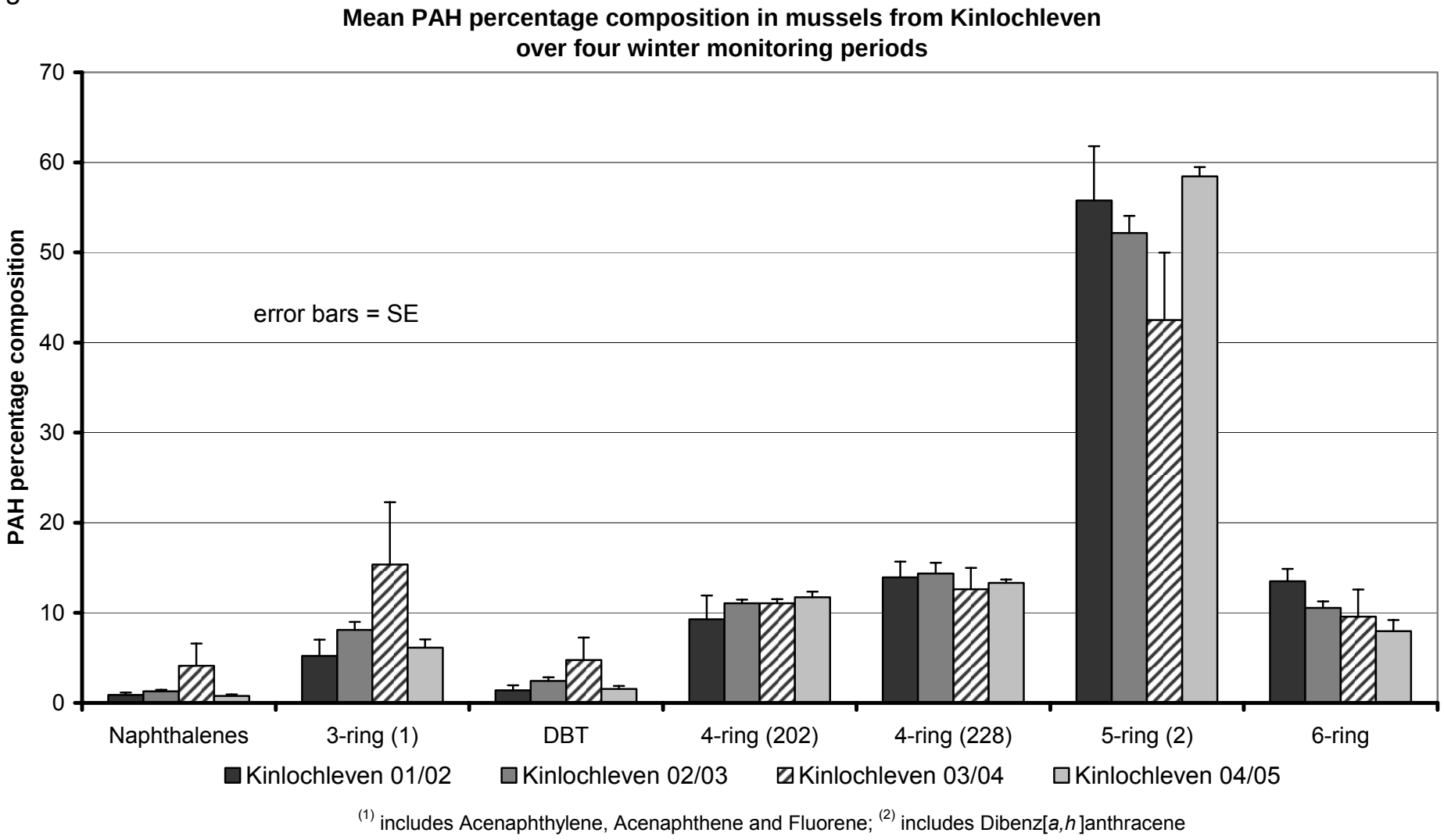
(1) includes Acenaphthylene, Acenaphthene and Fluorene; (2) includes Dibenz[*a,h*]anthracene

Figure 5a



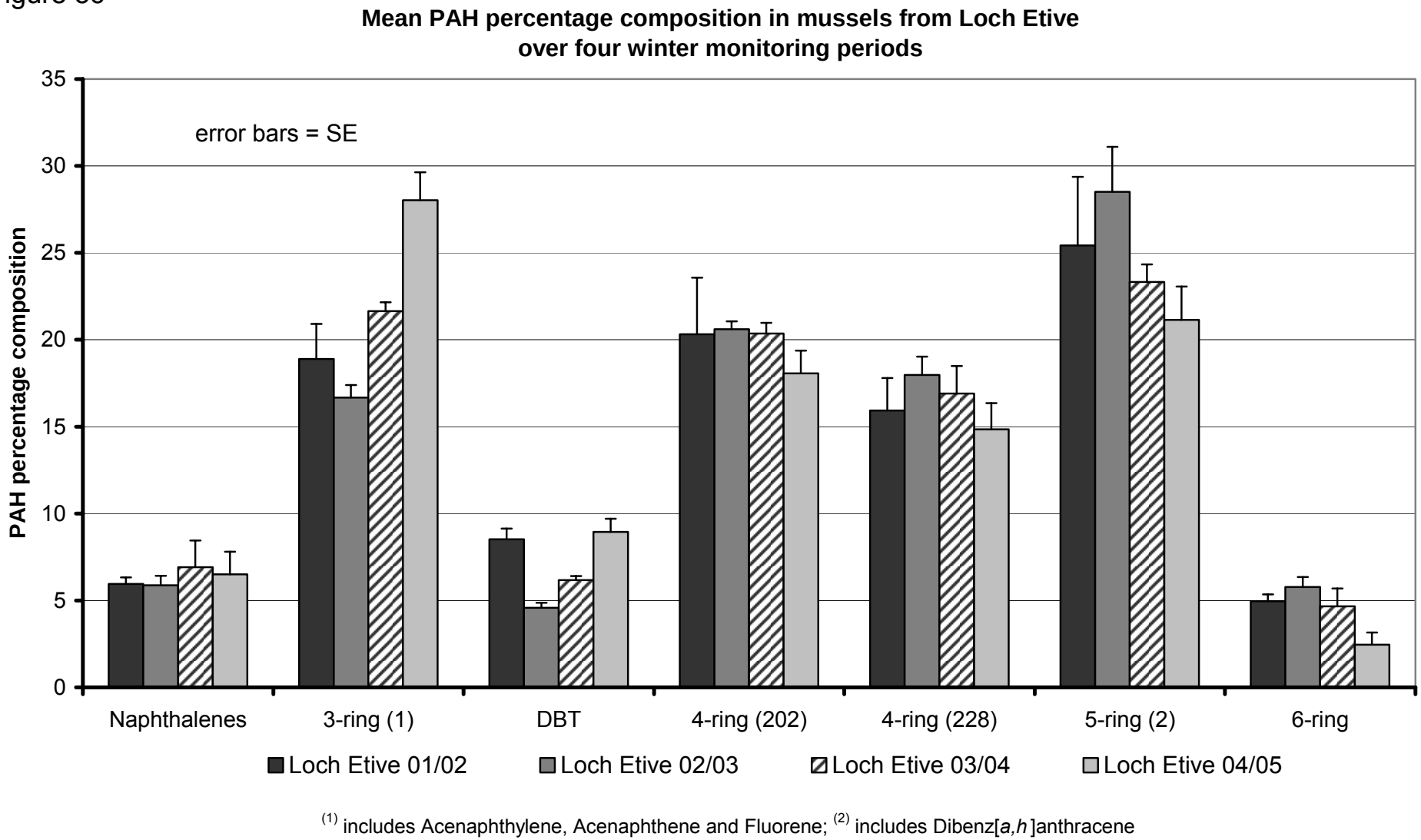
(1) includes Acenaphthylene, Acenaphthene and Fluorene; (2) includes Dibenz[*a,h*]anthracene

Figure 5b



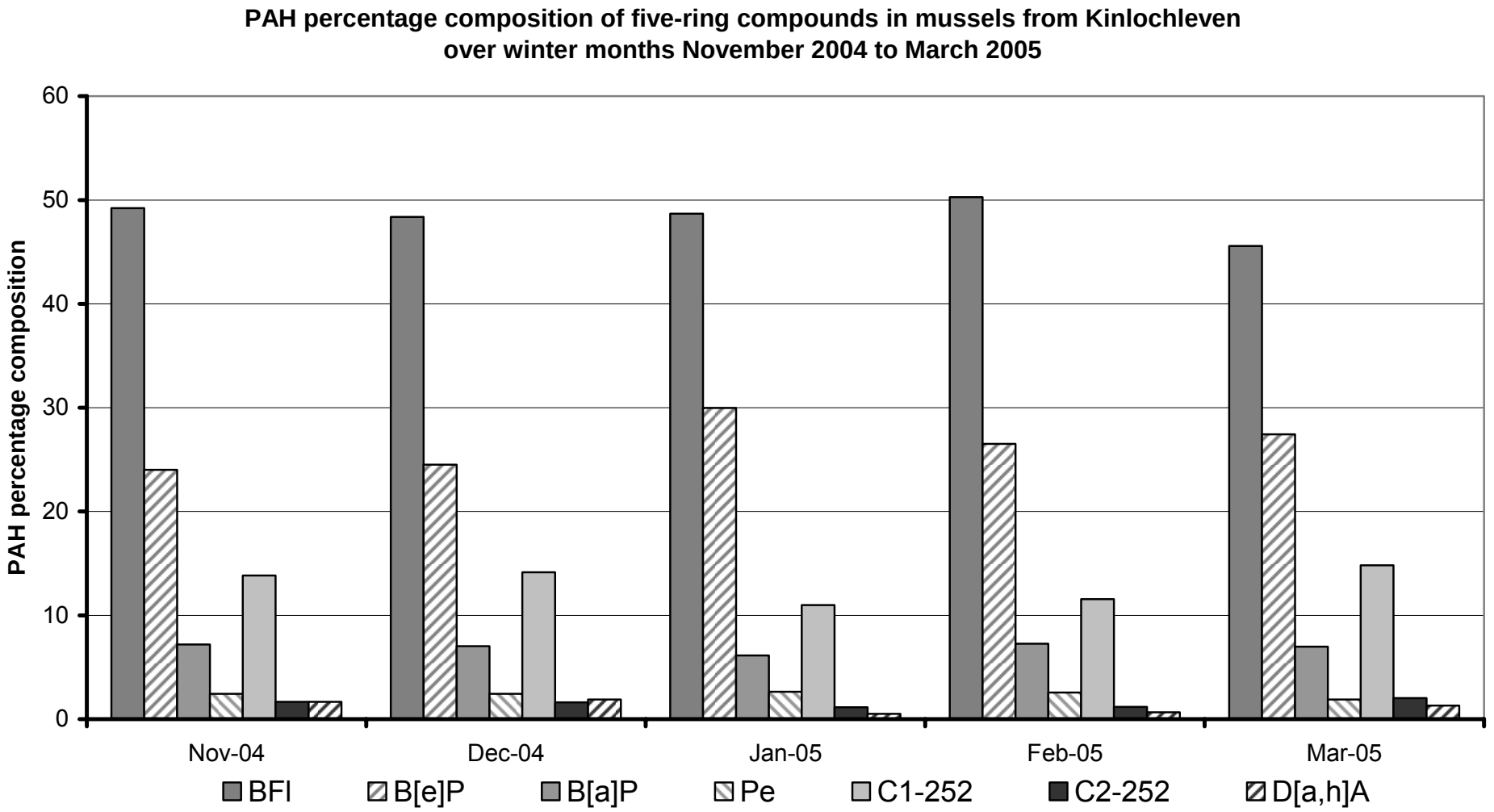
(1) includes Acenaphthylene, Acenaphthene and Fluorene; (2) includes Dibenz[*a,h*]anthracene

Figure 5c



(1) includes Acenaphthylene, Acenaphthene and Fluorene; (2) includes Dibenz[*a,h*]anthracene

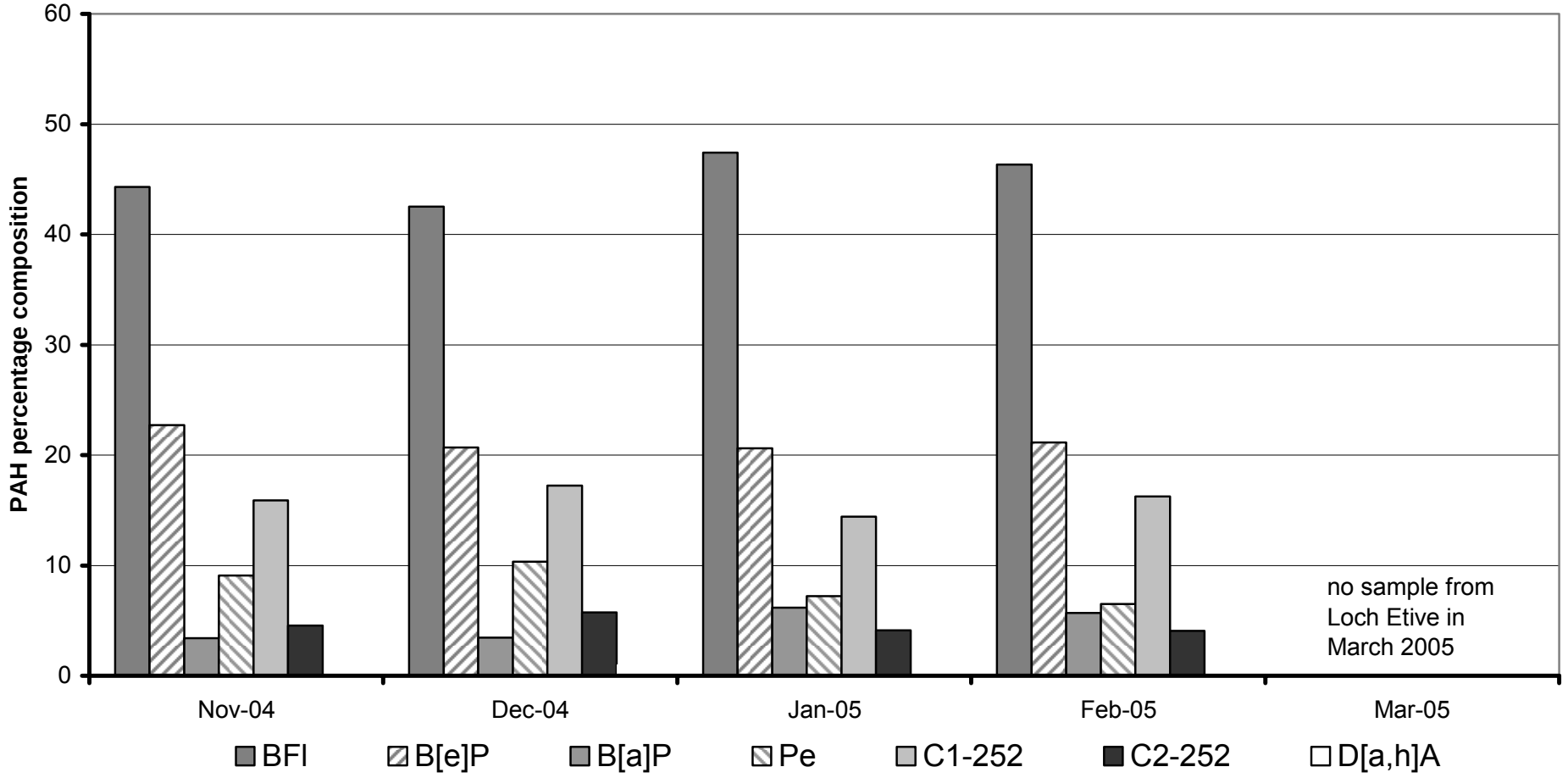
Figure 6a



BFl - combined benzo[*b*],[*k*] and [*j*]fluoranthenes; B[e]P - benzo[*e*]pyrene; B[a]P - benzo[*a*]pyrene; Pe - perylene; D[a,h]A - dibenz[*a,h*]anthracene

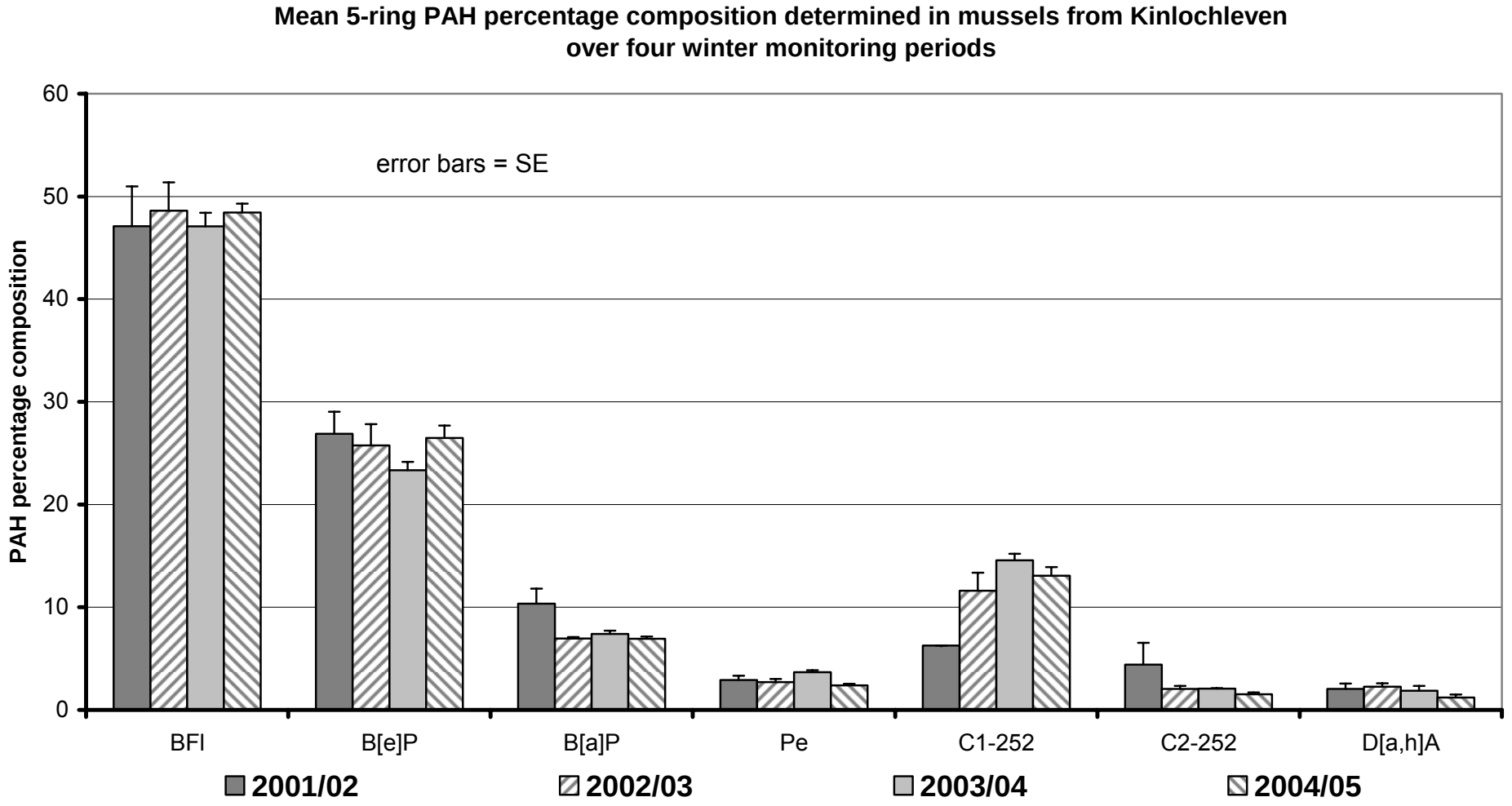
Figure 6b

PAH percentage composition of five-ring compounds in mussels from Loch Etive over winter months November 2004 to February 2005



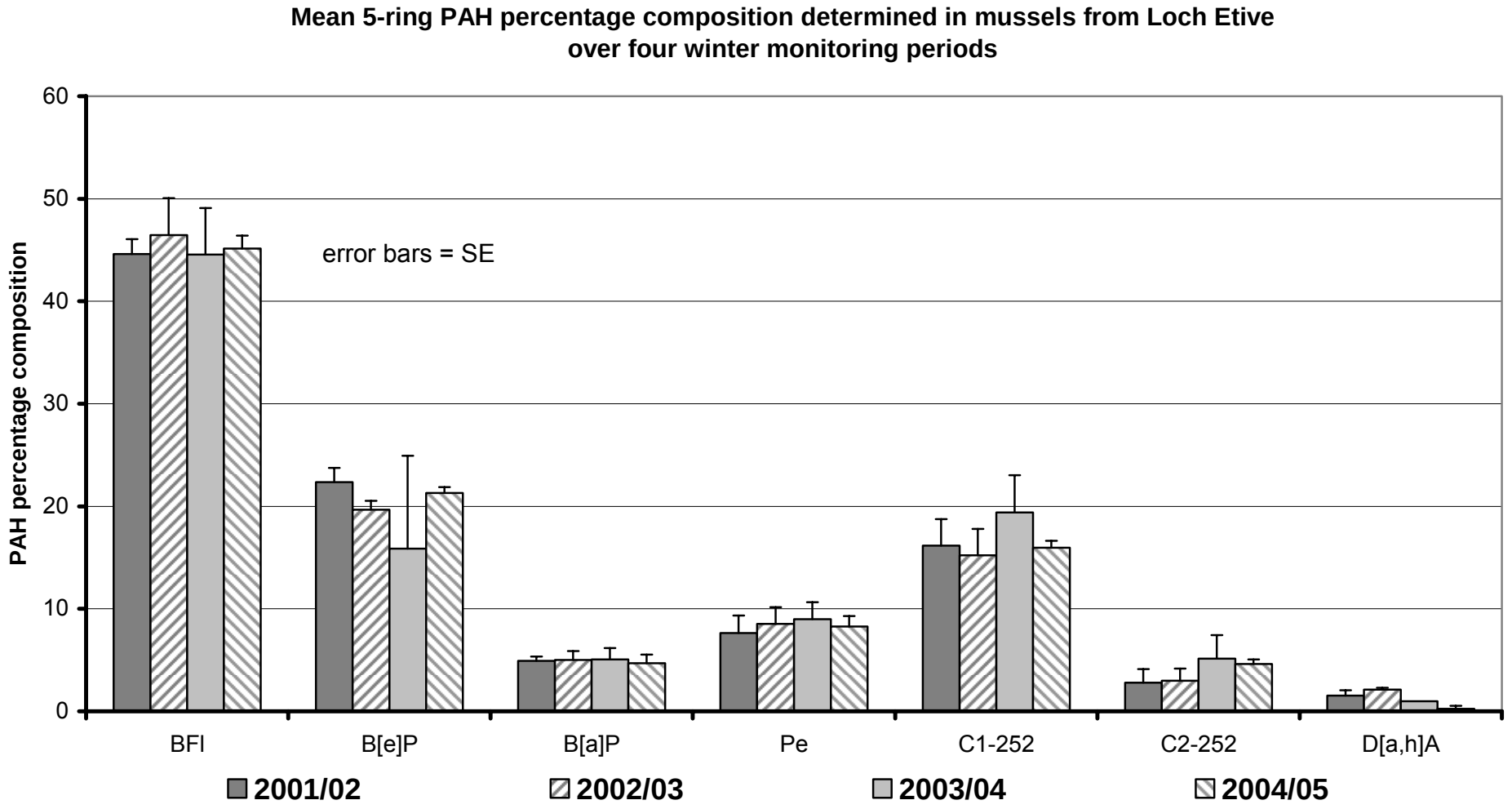
BFl - combined benzo[*b*],[*k*] and [*j*]fluoranthenes; B[e]P - benzo[*e*]pyrene; B[a]P - benzo[*a*]pyrene; Pe - perylene; D[a,h]A - dibenz[*a,h*]anthracene

Figure 7a



BFl - combined benzo[*b*],[*k*] and [*j*]fluoranthenes; B[e]P - benzo[*e*]pyrene; B[a]P - benzo[*a*]pyrene; Pe - perylene; D[a,h]A - dibenz[*a,h*]anthracene

Figure 7b



BFl - combined benzo[*b*],[*k*] and [*j*]fluoranthenes; B[e]P - benzo[*e*]pyrene; B[a]P - benzo[*a*]pyrene; Pe - perylene; D[a,h]A - dibenz[*a,h*]anthracene

Figure 8

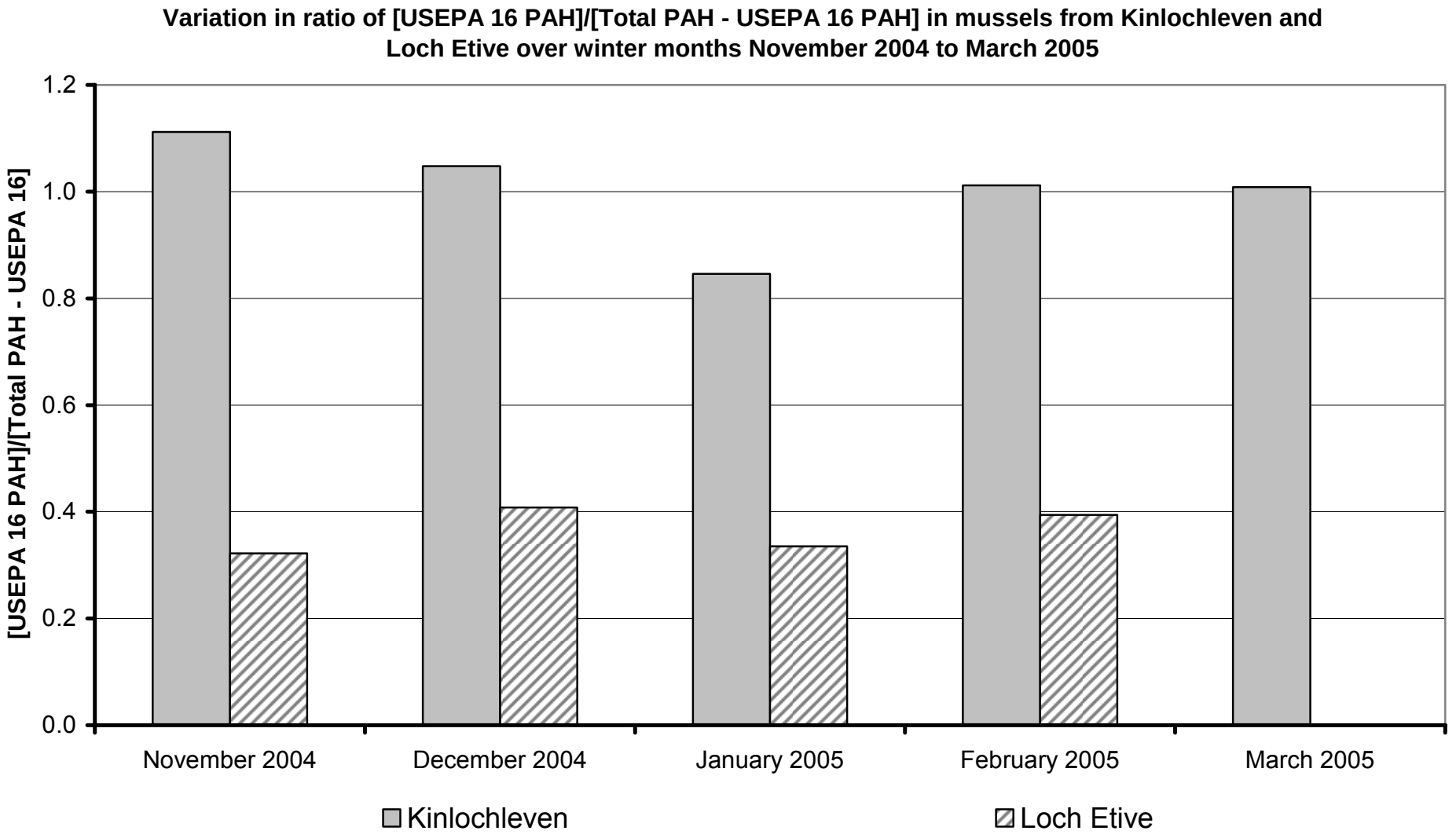

Variation in ratio of [USEPA 16 PAH]/[Total PAH - USEPA 16 PAH] in mussels from Kinlochleven and Loch Etive over winter months November 2004 to March 2005
[USEPA 16 PAH]/[Total PAH - USEPA 16]
1.2
1.0
0.8
0.6
0.4
0.2
0.0
November 2004
December 2004
January 2005
February 2005
March 2005
Kinlochleven
Loch Etive

Figure 9

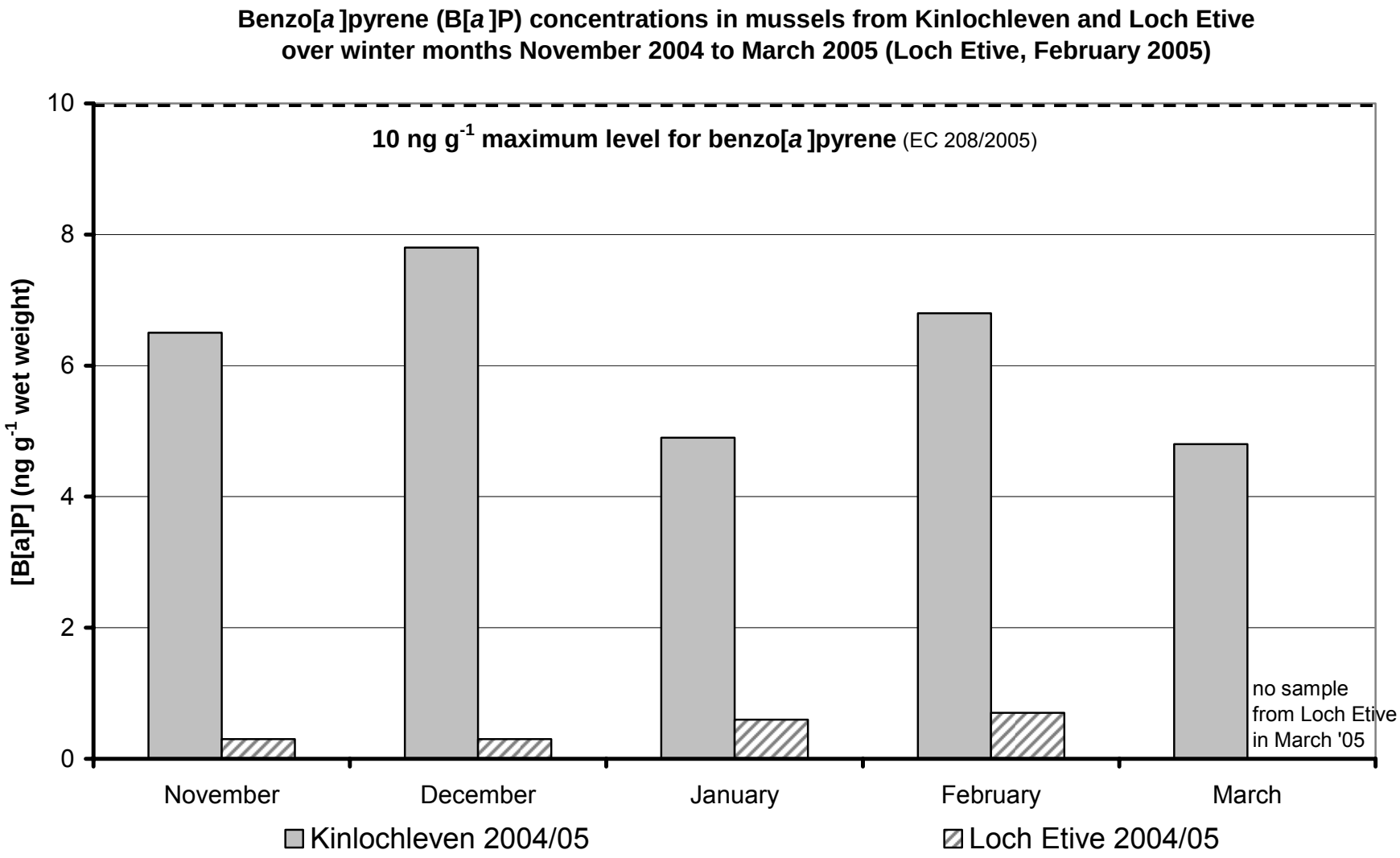
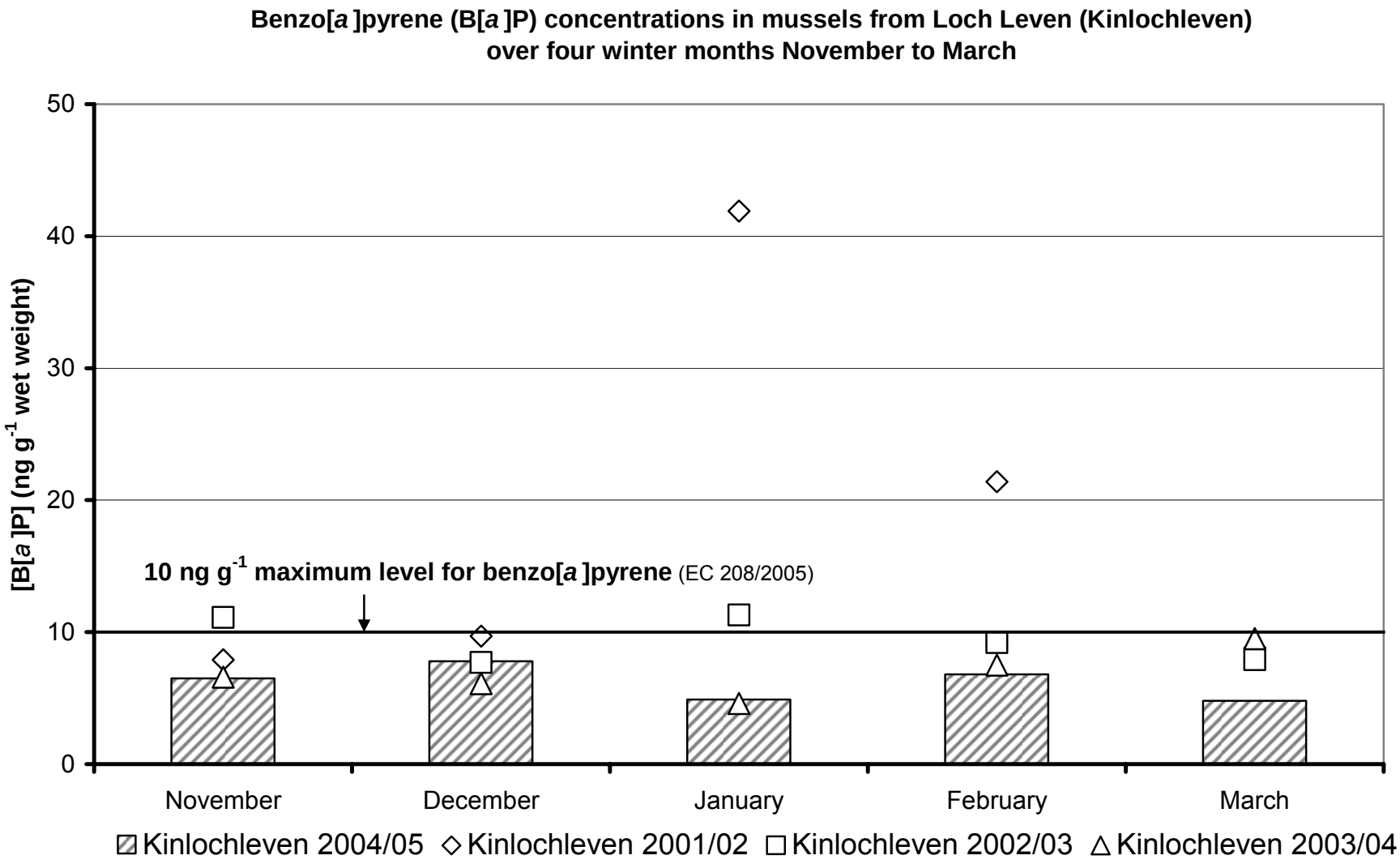

Benzo[a]pyrene (B[a]P) concentrations in mussels from Kinlochleven and Loch Etive over winter months November 2004 to March 2005 (Loch Etive, February 2005)
10 ng g-1 maximum level for benzo[a]pyrene (EC 208/2005)
[B[a]P] (ng g-1 wet weight)
10
8
6
4
2
0
November
December
January
February
March
no sample from Loch Etive in March '05
Kinlochleven 2004/05
Loch Etive 2004/05

Figure 10


Benzo[a]pyrene (B[a]P) concentrations in mussels from Loch Leven (Kinlochleven) over four winter months November to March
[B[a]P] (ng g-1 wet weight)
50
40
30
20
10
0
10 ng g-1 maximum level for benzo[a]pyrene (EC 208/2005)
November
December
January
February
March
Kinlochleven 2004/05
Kinlochleven 2001/02
Kinlochleven 2002/03
Kinlochleven 2003/04