Effect of heavy metal pollution on growth, carotenoid content and bacterial flora in the gut of *Perna viridis* (L.) in *in situ* condition

A. Tewari*, H. V. Joshi, C. Raghunathan, V. G. Sravan Kumar and Yasmin Khambhaty

Central Salt and Marine Chemicals Research Institute, Bhavnagar 364 002, India

The soft tissue of females of *Perna viridis* showed highest concentration of Fe, Mn, Cu, Zn, Cd, Pb, Co, Ni and Hg followed by males and indeterminates. The Hg was not detected in different sexes during May. The biomagnification of all heavy metals was maximum in gonad. In general, the order of metal accumulation in the soft tissue of *Perna viridis* was – Fe > Co > Zn > Pb > Ni > Cu > Mn > Cd > Hg. The definite correlation between biomagnification of different heavy metals in whole animal or its different organs could not be observed with that of their concentrations in sediment. However, the concentration of all heavy metals was higher in soft tissue or its different organs than sea water. The concentration of total carotenoids and unsaponifiable carotenoid were higher in females followed by males and indeterminates. Both types of carotenoids in gonads had higher concentration than other body organs. In general, the total count of pathogenic bacteria was maximum in the gut of females followed by indeterminates and males. The percentage reduction of pathogenic bacteria after five days of starvation ranged from 28.92 to 42.81 in the least reduction category to 61.59 to 75.25 for the highest reduction category.

PERNA *viridis* is an important marine food in India. Both natural and cultured mussels are utilized for food[1–3]. The total production of *P. viridis* during the year 1995–1996 to 1999–2000 varied between 2472 and 5675 MT/year. This includes 90–600 MT obtained by artificial cultivation. In India, the retail cost of the *P. viridis* varies from place to place and it ranges between Rs 5 and 10/kg (Appukuttan, K. K., Central Marine Fisheries Research Institute, Cochin; pers. commun.). *P. viridis* has been reported from Mocha, Gujarat, south-west coast of India[4] and also from Dwarka. Mocha is a small coastal village near the port of Porbandar. The latter has big alkali, fishing and chalk processing industries and its coastal waters are polluted by these industries. Dwarka is a pilgrimage town and its waters are affected by domestic sewage and fish-processing industry. Domestic sewage, fish-processing industries and port activities are the major source of heavy metals and bacterial contamination in this area. *P. viridis* has widespread distribution in Indian coastal waters[5,6].

Several bivalves, including *Perna* species have the ability to accumulate heavy metals from sea water. Similar studies from the east coast[7,8] and the west coast of India[4,9–12] have been reported. Similar reports are also available from several other countries[13–17]. These organisms have also been used for monitoring the heavy metals contamination[18–25].

The carotenoid content of *P. viridis* and other molluscs and its relationship with pollution has been reported. Molluscs having high carotenoid content are strongly-resistant to environmental pollution[26–28].

The bacterial composition of green mussel and sea water is reported[29–31]. Since *P. viridis* is consumed as human food and it is also reported that sea water is contaminated with human pathogen[32], and such reports are not available for species of *Perna* from the Gujarat coast, therefore it was decided to undertake the present study.

P. viridis (Linnaeus) were collected from their natural habitat at Mocha (lat. 21°20′N, long. 69°53′E) and Dwarka (lat. 22°25′N, long. 69°04′E), Saurashtra, west coast of India, during May, August and November 2000. They were collected from 0.2 m below the zero of the *chart datum*. Soon after collection, the epiphytic flora and fauna on the surface of the shell were thoroughly removed and washed with clean sea water. Twenty-five individuals each from males, females and indeterminates were collected randomly, for determination of size variations in the population during May, August and November 2000. The morphometric measurements like length and width were made using vernier caliper with an accuracy of 0.5 mm. Total weight, soft tissue weight of mantle, gonad and adductor muscle were also measured in live organisms, just after collection. Sexes were identified by colour of the gonad – bright orange for females, whitish-yellow for males and cream for indeterminates.

The whole gut was divided into three equal parts, fore, mid and hind guts, respectively. Each class of gut was aseptically transferred to a sterile weighing bottle and weighed immediately after dissection. Later, each portion of the gut was transferred to separate sterile test tubes containing 10 ml of sterile sea water having 5% Tween-80. These tubes were shaken on a rotary shaker having 150 rotations per minute. The different groups/species of bacteria were determined in sea water according to a method described earlier[33]. The bacterial count was calculated on the basis of fresh weight of the gut. The bacterial analyses of sea water and sediment were also performed simultaneously.

The starvation studies were performed by maintaining freshly-collected mussels in sterile sea water for 5 days. Sea water was changed daily. Later, the bacterial analysis of the gut was studied, as described above.

*For correspondence. (e-mail: salt@csir.res.in)

Considerable number of mussels from all three sexes were brought to the laboratory in ice-cold condition, where they were utilized for the estimation of heavy metals and carotenoid contents. For heavy metal analysis 10 mussels each of males, females and indeterminates were used. The whole soft tissue of the mussel was removed using a teflon forceps. The whole soft tissue and different organs such as mantle, gonad and adductor muscle were dissected separately for each sex group and rinsed with deionized water. Each sample was dried in an oven at 95°C for heavy metal determination, till constant weight. However, for carotenoid estimation, they were dried at 55°C. Later, they were ground to find powder. The 100 μ mesh-sized powder was used for estimation of heavy metals and carotenoids. The heavy metals in *P. viridis* and sea water were estimated according to the method presented earlier[33]. The total and unsaponifiable carotenoids were estimated spectrophotometrically, by the method described by Karnaukhov *et al.*[26]. The carotenoid concentration was calculated according to the formula given below[26].

$$\text{mg/100 g} = 0.4 \times DV \times P,$$

where D is the optical density of the extract in 1 cm (thickness) cuvette, V is the total volume of carotenoid extract in ml, and P is the total dry weight of tissue from which carotenoids were extracted.

The seasonal variation of growth of *P. viridis* at Mocha and Dwarka is presented in Table 1. The total weight, tissue weight and weights of mantle, gonad and adductor muscle in males, females and indeterminates of mussel increased continuously from May to November, both at Mocha and Dwarka. The total weight of the males was maximum at Mocha and Dwarka during different months of the study. However, the trend for females and indeterminates was different at Mocha and Dwarka. The soft tissue weight was maximum in females followed by males and indeterminates, at both Mocha and Dwarka during all three months, except during May at Mocha. The relative weights of the mantle, gonad and adductor muscle in *P. viridis* showed that the adductor muscle has the highest weight followed by the gonad and mantle in all three sexes and seasons, both at Mocha and Dwarka, except where the mantle had higher weight than gonad in indeterminates during all three months at Mocha. The width of the animals was maximum in males followed by indeterminates and females, during all three months at Dwarka and during November at Mocha. However, at Mocha the maximum width was observed in indeterminates followed by males and females, during May and August.

Table 1. Seasonal variation of growth of different sexes of *Perna viridis* from Mocha and Dwarka (length and width in mm; wet weight in g)

	Mocha			Dwarka		
Parameter	May	August	November	May	August	November
Sex ratio (male : female : indeterminate)	1 : 1.80 : 0.57	1 : 1.10 : 0.50	1 : 0.83 : 0.42	1 : 0.64 : 0.57	1 : 1.59 : 0.42	1 : 1.90 : 0.84
Male						
Length	45.21 ± 2.26	68.38 ± 2.53	90.57 ± 2.72	92.52 ± 1.86	108.31 ± 2.01	121.15 ± 1.90
Width	27.86 ± 2.64	42.52 ± 2.13	49.38 ± 2.28	45.50 ± 1.24	53.51 ± 1.84	55.45 ± 2.02
Total weight	12.51 ± 1.04	16.90 ± 1.82	50.28 ± 1.52	54.04 ± 1.80	82.17 ± 2.12	135.14 ± 2.85
Soft tissue weight	3.90 ± 0.38	6.95 ± 0.42	11.24 ± 0.87	12.23 ± 0.92	21.73 ± 1.20	28.99 ± 1.80
Mantle weight	0.52 ± 0.11	1.07 ± 0.23	1.21 ± 0.22	1.32 ± 0.21	3.81 ± 0.25	4.90 ± 0.64
Gonad weight	0.72 ± 0.08	1.28 ± 0.60	2.23 ± 0.40	2.49 ± 0.33	4.85 ± 0.42	6.51 ± 0.72
Adductor muscle weight	1.31 ± 0.22	2.92 ± 0.72	4.42 ± 0.84	4.03 ± 0.23	5.96 ± 0.72	8.50 ± 0.52
Female						
Length	44.26 ± 2.52	67.41 ± 2.22	88.31 ± 2.00	91.53 ± 1.75	106.56 ± 2.52	120.25 ± 2.31
Width	26.23 ± 2.21	40.72 ± 2.00	47.47 ± 2.40	42.52 ± 1.42	51.28± ± 1.25	52.16 ± 1.75
Total weight	11.28 ± 1.20	14.27 ± 2.02	43.82 ± 2.80	50.38 ± 1.78	78.52 ± 2.15	122.52 ± 2.54
Soft tissue weight	4.31 ± 0.40	7.81 ± 0.52	13.07 ± 0.75	14.50 ± 0.67	26.82 ± 1.35	32.56 ± 1.28
Mantle weight	0.76 ± 0.37	1.23 ± 0.80	2.31 ± 0.35	2.00 ± 0.22	4.21 ± 0.52	5.15 ± 0.62
Gonad weight	0.90 ± 0.22	2.00 ± 0.27	3.81 ± 0.72	3.15 ± 0.42	5.25 ± 0.52	7.56 ± 0.52
Adductor muscle weight	1.57 ± 0.30	3.25 ± 0.66	5.31 ± 0.33	5.21 ± 0.36	6.28 ± 0.60	7.81 ± 0.81
Indeterminate						
Length	46.07 ± 2.70	68.21 ± 2.56	90.32 ± 2.82	91.81 ± 2.15	108.52 ± 2.25	120.18 ± 2.00
Width	28.21 ± 2.04	43.28 ± 2.21	48.73 ± 2.38	43.52 ± 1.52	52.51 ± 2.25	55.07 ± 2.08
Total weight	11.83 ± 1.15	15.83 ± 1.21	40.52 ± 1.82	50.03 ± 1.78	76.28 ± 2.10	130.56 ± 2.52
Soft tissue weight	3.95 ± 0.41	6.52 ± 0.37	11.00 ± 0.72	11.46 ± 0.72	19.23 ± 1.28	25.68 ± 2.70
Mantle weight	0.53 ± 0.09	1.20 ± 0.27	1.30 ± 0.23	1.25 ± 0.15	2.56 ± 0.23	3.89 ± 0.28
Gonad weight	0.52 ± 0.18	1.01 ± 0.21	0.30 ± 0.30	1.85 ± 0.35	2.78 ± 0.40	4.81 ± 0.75
Adductor muscle weight	1.03 ± 0.30	2.23 ± 0.70	4.87 ± 0.32	4.08 ± 0.41	5.75 ± 0.85	8.00 ± 1.02

The male–female ratio ranged from 1 : 0.83 to 1 : 1.8 at Mocha and 1 : 0.64 to 1 : 1.90 at Dwarka, during different periods of study. The male–female ratio continuously declined from May to November at Mocha, while a reverse trend was observed at Dwarka. The male–indeterminate ratio ranged from 1 : 0.4 to 1 : 0.6 at Mocha and 1 : 0.42 to 1 : 0.85 at Dwarka. The male–indeterminate ratio continuously increased from May to November at Dwarka, while at Mocha, it did not show a clear trend of variation. A definite trend of variation for length of *P. viridis* was not observed for different sexes and seasons at both the places of study.

Bioaccumulation of iron, manganese, copper, zinc, nickel, cadmium, lead, cobalt and mercury in different sexes and organs of *P. viridis* during different seasons, at Mocha and Dwarka, are presented in Tables 2 and 3. The entire soft tissue of females showed higher concentration of all the heavy metals followed by males and indeterminates, during different months at Mocha ($P < 0.05$, $r = 0.1$) and Dwarka ($P < 0.01$, $r = 0.1$). Mercury was not detected in different sexes during May, both at Mocha ($P < 0.05$, $r = 0.1$) and Dwarka ($P < 0.01$, $r = 0.1$). The biomagnification of Fe, Mn, Cu, Zn and Ni was maximum in the gonad followed by the mantle and adductor muscle, in different sexes of *P. viridis* during different seasons at Mocha ($P < 0.05$, $r = 0.1$) and Dwarka ($P < 0.01$, $r = 0.1$). However, Cd, Pb and Co biomagnification was maximum in the gonad followed by adductor muscle and mantle during different months and sexes, at Mocha and Dwarka. Mercury was not detected during May in all the sexes of *P. viridis*, from Mocha and Dwarka. No definite trend of variation in mercury was observed in different sexes

Table 2. Seasonal variation of heavy metals accumulation by different sexes and organs of *P. viridis* at Mocha (μg g^{-1})

	Fe			Mn			Cu			Zn			Cd		
Sample	May	August	Nov.	May	August	Nov.	May	August	Nov.	May	August	Nov.	May	August	Nov.
Sea water (μg l^{-1})	42.21	54.58	47.00	1.60	4.470	2.28	5.48	5.44	5.68	2.99	3.08	2.90	1.01	2.17	0.98
Sediment	191.20	230.50	200.17	23.22	26.12	21.35	39.45	44.15	46.42	17.20	22.24	12.11	0.92	3.69	2.16
Male															
Whole soft tissue	241.33	281.35	276.52	7.35	14.28	10.56	8.23	12.31	15.70	44.23	72.60	59.38	1.58	3.18	2.90
Mantle	459.57	620.10	531.30	12.52	27.54	19.24	15.62	23.25	3.21	60.21	96.72	78.32	2.03	5.17	3.45
Gonad	623.55	902.23	837.32	20.31	41.28	29.76	24.35	38.54	46.21	73.04	115.28	90.31	5.86	13.27	9.21
Adductor muscle	287.38	387.42	310.85	10.07	19.87	13.85	10.17	18.09	20.24	51.86	81.76	65.21	3.11	8.21	6.24
Female															
Whole soft tissue	262.24	302.25	285.34	10.23	16.28	13.31	12.58	16.58	21.22	53.21	82.80	64.33	2.88	4.20	3.71
Mantle	494.50	721.72	681.31	19.44	34.06	27.81	22.60	30.00	38.49	69.07	101.74	90.21	3.47	7.87	5.09
Gonad	832.50	1120.81	1007.51	28.34	52.53	41.27	35.80	50.21	59.82	85.30	127.80	103.83	9.00	16.81	12.28
Adductor muscle	260.31	442.89	324.85	13.25	21.58	20.34	17.29	21.06	29.21	62.85	92.31	71.59	5.38	10.26	8.64
Indeterminate															
Whole soft tissue	230.58	279.31	260.78	5.25	12.21	8.25	6.82	8.31	11.26	40.23	61.71	55.01	1.08	2.98	2.59
Mantle	425.52	618.52	584.34	11.24	23.91	17.20	13.07	17.25	24.35	53.84	73.84	71.24	1.89	4.67	3.45
Gonad	529.30	692.07	602.83	16.28	34.81	24.00	20.19	26.32	35.40	65.86	97.81	83.25	3.80	10.82	8.88
Adductor muscle	223.74	340.53	285.83	9.71	18.07	12.31	9.25	11.32	19.20	47.80	68.52	62.18	2.80	6.37	5.31

	Pb			Co			Ni			Hg		
Sample	May	August	Nov.	May	August	Nov.	May	August	Nov.	May	August	Nov.
Sea water (μg l^{-1})	0.98	1.29	1.28	0.98	1.10	1.01	0.98	0.99	1.22	ND	< 0.10	< 0.10
Sediment	26.42	46.42	31.33	59.36	48.56	35.56	54.23	68.84	72.16	< 0.1	0.10	0.10
Male												
Whole soft tissue	35.26	55.86	42.34	65.26	101.83	83.45	23.28	36.45	41.75	ND	0.03	0.05
Mantle	42.51	63.81	53.28	79.70	119.28	97.24	46.21	59.81	84.49	ND	ND	0.03
Gonad	71.24	96.34	80.21	123.44	192.31	156.27	60.37	92.32	120.82	ND	0.06	0.10
Adductor muscle	53.28	80.25	62.77	97.62	147.13	107.22	25.14	42.84	60.28	ND	ND	ND
Female												
Whole soft tissue	41.52	63.84	50.11	73.64	112.14	90.10	30.25	42.37	53.15	ND	0.08	0.10
Mantle	53.26	75.38	60.20	91.53	133.44	109.81	59.83	78.22	100.33	ND	ND	0.03
Gonad	85.26	113.30	102.52	142.56	207.34	175.82	91.52	125.08	169.29	ND	0.1	0.15
Adductor muscle	60.44	96.21	78.22	110.33	169.86	133.82	38.24	61.80	73.55	ND	ND	0.09
Indeterminate												
Whole soft tissue	30.56	46.42	38.21	59.44	88.07	71.40	19.50	27.27	34.45	ND	0.02	0.03
Mantle	42.04	50.26	47.54	69.27	103.05	86.24	35.24	51.08	65.36	ND	0.04	0.06
Gonad	67.30	78.62	73.81	112.21	171.12	134.00	57.28	72.82	89.25	ND	ND	ND
Adductor muscle	51.50	62.17	55.25	88.27	122.83	106.24	23.84	38.33	48.07	ND	ND	ND

during different seasons, at Mocha and Dwarka. The results clearly indicate that the concentration of mercury is highest in the gonad, wherever it is detected. The other heavy metals also showed highest concentration in the gonad compared to other organs, at Mocha ($P < 0.05$, $r = 0.1$) and Dwarka ($P < 0.01$, $r = 0.1$). The maximum bioaccumulation of all the heavy metals, except Cu and Ni, in all sexes and organs was observed during August. In case of Cu and Ni, it was during November. However, the minimum concentration of all the heavy metals in the soft tissue and different organs during different months and places was observed during summer (May). The bioaccumulation of Fe, Zn, Pb and Co in soft tissue of *P. viridis* was higher during all seasons and sexes compared to the sediment, at Mocha ($P < 0.05$, $r = 0.1$) and Dwarka ($P < 0.01$, $r = 0.1$). However, reverse trend was observed for Cu and Hg, whereas no definite trend could be observed for Mn, Cd and Ni. Biomagnification of Fe, Zn, Cd, Pb, Co and Ni (gonad only) was higher in the mantle, adductor muscle and gonad compared to the sediment. However, Hg was higher in the sediment compared to the mantle and adductor muscle. Mn, Cu and Ni did not show any definite trend of variation in the mantle and adductor muscle. Similarly, Mn, Cu and Hg also did not show any definite trend in the gonad compared to the sediment. Although the concentration ($\mu g\ l^{-1}$) of these metals in sea water cannot be strictly compared with that of *P. viridis* ($\mu g\ g^{-1}$), however, a definite correlation has been observed with these two independent variables. The data indicate that the bioaccumulation of the heavy metals was always higher in different sexes and their body organs during different seasons, compared to sea

Table 3. Seasonal variation of heavy metals accumulation by different sexes and organs of *P. viridis* from Dwarka ($\mu g\ g^{-1}$)

	Fe			Mn			Cu			Zn			Cd		
Sample	May	August	Nov.	May	August	Nov.	May	August	Nov.	May	August	Nov.	May	August	Nov.
Sea water ($\mu g\ l^{-1}$)	71.80	83.07	70.51	3.00	5.61	3.22	5.61	6.66	5.70	3.49	3.67	3.22	2.15	2.19	2.17
Sediment	224.31	250.37	241.80	22.30	26.10	21.30	39.45	44.15	46.42	20.22	29.31	17.9s2	1.73	3.52	0.92
Male															
Whole soft tissue	432.83	528.45	487.34	13.21	20.82	15.35	16.32	20.31	24.48	58.52	90.31	72.25	3.51	7.21	5.54
Mantle	585.08	729.34	621.56	25.25	37.56	28.31	31.57	41.52	50.27	80.37	132.30	97.33	4.32	10.26	7.55
Gonad	789.20	1120.53	845.55	38.25	63.24	48.70	50.55	58.24	65.37	120.20	170.00	148.28	9.25	20.52	16.20
Adductor muscle	454.26	607.38	582.35	20.15	26.50	21.80	20.66	27.68	33.81	67.35	109.20	81.58	6.58	13.52	11.26
Female															
Whole soft tissue	559.85	618.25	591.38	17.32	29.54	22.89	20.31	28.97	40.47	70.50	92.54	83.07	5.32	9.48	6.89
Mantle	703.85	927.18	725.25	33.86	56.75	41.52	43.26	53.85	91.35	102.82	152.80	116.21	7.33	11.24	9.33
Gonad	873.56	1218.53	985.50	50.75	86.50	60.87	58.37	86.52	117.20	143.27	183.82	158.52	16.28	30.00	21.37
Adductor muscle	588.54	709.23	612.83	22.45	40.29	27.38	26.59	40.55	59.95	91.35	125.34	96.54	12.36	19.17	13.15
Indeterminate															
Whole soft tissue	389.42	481.35	402.85	12.52	18.92	13.04	14.24	17.34	21.86	52.62	813.28	68.84	2.54	6.25	4.21
Mantle	520.35	669.57	585.28	23.37	31.75	29.00	30.31	32.25	39.27	73.85	110.25	91.69	4.39	9.37	5.45
Gonad	639.85	957.83	727.48	35.64	52.37	39.25	45.46	53.00	58.22	97.63	155.20	130.55	6.25	18.42	12.31
Adductor muscle	405.30	523.08	488.31	17.68	23.15	18.52	19.15	21.66	28.06	60.56	95.20	75.50	3.46	12.00	8.37

	Pb			Co			Ni			Hg		
Sample	May	August	Nov.	May	August	Nov.	May	August	Nov.	May	August	Nov.
Sea water ($\mu g\ l^{-1}$)	3.33	3.39	3.34	2.10	2.51	2.01	1.55	1.60	1.66	0.1	ND	0.10
Sediment	26.42	46.42	31.33	42.56	52.31	26.11	38.44	38.26	44.23	0.1	0.10	0.10
Male												
Whole soft tissue	50.21	72.25	61.84	72.97	113.85	94.53	35.28	41.52	53.46	ND	0.08	0.04
Mantle	59.33	76.21	62.34	92.67	121.00	100.25	62.59	60.27	61.21	ND	0.10	ND
Gonad	81.30	93.28	88.59	140.25	172.00	158.28	80.21	85.27	97.25	ND	0.10	0.10
Adductor muscle	66.27	80.56	76.21	124.29	149.20	131.32	43.85	42.10	50.51	ND	ND	ND
Female												
Whole soft tissue	60.40	92.38	78.56	80.30	128.83	105.50	40.54	53.82	65.45	ND	0.10	0.06
Mantle	68.50	84.21	77.26	106.25	130.35	111.35	72.02	80.15	95.20	ND	0.09	0.08
Gonad	97.31	103.52	94.85	159.83	190.07	170.86	97.56	103.21	115.26	ND	0.10	0.10
Adductor muscle	78.47	90.35	83.75	138.00	186.08	144.20	40.30	61.27	70.21	ND	0.07	ND
Indeterminate												
Whole soft tissue	45.28	63.84	57.55	62.34	98.53	75.58	32.81	40.58	48.67	ND	0.07	0.03
Mantle	50.51	62.20	58.33	85.54	110.25	82.33	51.38	74.25	63.00	ND	0.05	0.08
Gonad	72.37	80.50	69.75	133.35	152.35	123.50	63.87	93.50	80.29	ND	ND	ND
Adductor muscle	58.10	70.00	63.80	113.76	135.30	97.30	40.20	51.75	51.29	ND	0.10	ND

water. The order of metal accumulation in the soft tissue of *P. viridis* (all sexes, months and places) was: Fe > Co > Zn > Pb > Ni > Cu > Mn > Cd > Hg. However, a very minor deviation was observed during August in some sexes, where Cu > Mn trend was replaced by Mn > Cu trend and November, when Pb > Ni trend was also reversed.

The seasonal variation of total carotenoids and unsaponifiable carotenoids in *P. viridis* at Mocha and Dwarka are depicted in Figures 1 and 2. The concentration of total carotenoids was always higher in females followed by males and indeterminate animals, during different months, at Mocha ($P < 0.05$, $r = 0.1$) and Dwarka ($P < 0.01$, $r = 0.1$). A similar trend of variation was observed, both at Mocha and Dwarka, for unsaponifiable carotenoids, except during August at Mocha, when indeterminate animals had higher concentration, followed by males and females.

The total carotenoid concentration of different organs was the highest in the gonad followed by the mantle and adductor muscle, for all months and all sexes, at Mocha ($P < 0.05$, $r = 0.1$) and Dwarka ($P < 0.01$, $r = 0.1$), except in indeterminate animals, where a maximum value was observed in the mantle, followed by the gonad and adductor muscle during November at Mocha. Similar trends of variation were observed for unsaponifiable carotenoid also, except for indeterminate animals, where the maximum was observed in the mantle followed by the gonad and adductor muscle, during all three months at Mocha. The maximum total and unsaponifiable carotenoid contents were observed during August in soft tissue, different organs and different sexes, both at Mocha ($P < 0.05$, $r = 0.1$) and Dwarka ($P < 0.01$, $r = 0.1$).

The count of pathogenic and non-pathogenic bacteria in the gut of *P. viridis* in *in situ* condition is presented in Tables 4 and 5. In general, the total viable count was maximum in the hind gut followed by fore gut and mid gut, in all the sexes and seasons at Mocha ($P < 0.05$, $r = 0.1$) and Dwarka ($P < 0.01$, $r = 0.1$). However, females at Mocha during May and indeterminates at Dwarka during August and November showed a different trend. The maximum count of total viable count was observed in November for all sexes and different regions of the gut, both at Mocha ($P < 0.05$, $r = 0.1$) and Dwarka ($P < 0.01$, $r = 0.1$). The maximum count of *Pseudomonas aeruginosa*, was recorded in the hind gut followed by mid gut and fore gut, in different sexes in different months, except indeterminates and males at Dwarka during May. The total coliforms, *Escherichia coli*, *Shigella, Salmonella, Proteus/Klebsiella, Vibrio cholerae, Vibrio parahaemolyticus,* other *Vibrios* and *Streptococcus faecalis* did not show clear trend of variation in different sexes and different regions of the gut during different months, at Mocha and Dwarka. The total count of pathogenic bacteria in

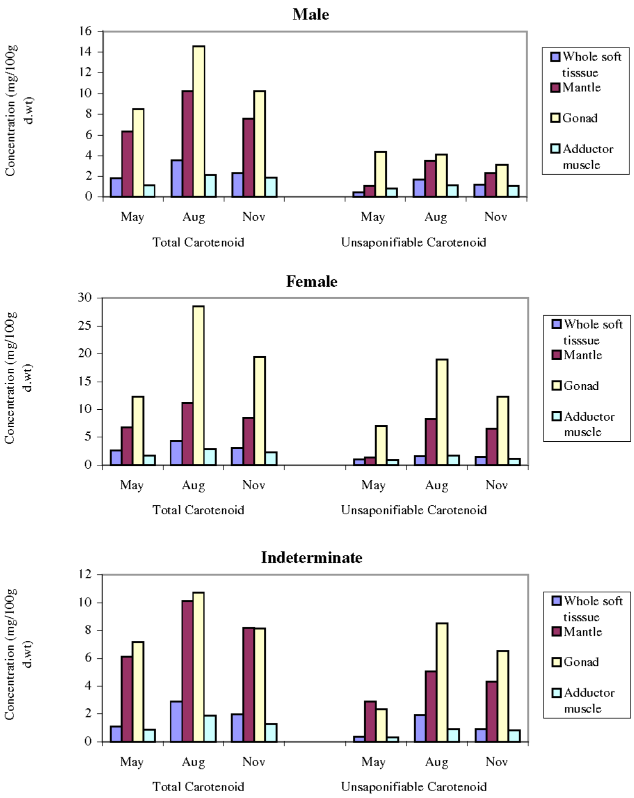

Figure 1. Carotenoid concentration in different seasons and sexes in *P. viridis* at Mocha.

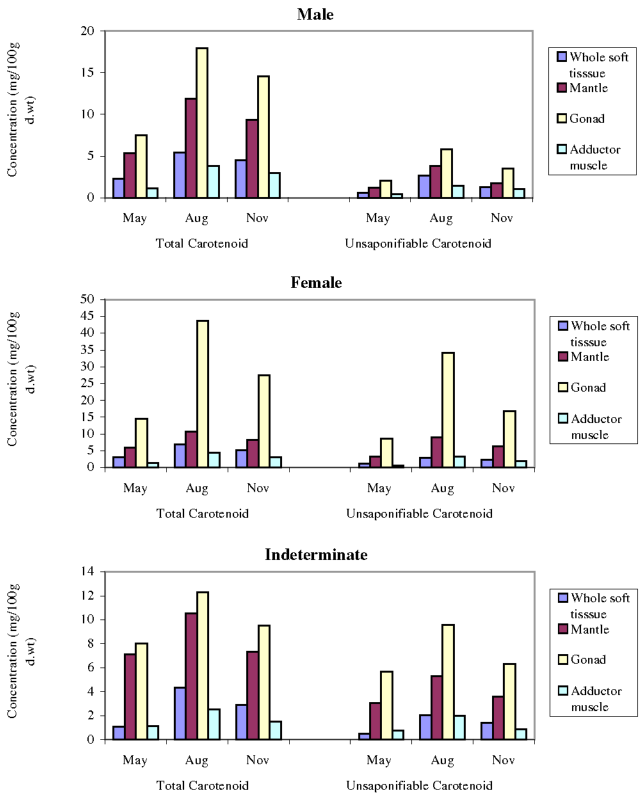

Figure 2. Carotenoid concentration in different seasons and sexes in *P. viridis* at Dwarka.

males and indeterminates progressively increased from fore gut to hind gut at both the places of study from May to November ($P < 0.05$, $r = 0.1$ for Mocha and $P < 0.01$, $r = 0.1$ for Dwarka). However, females showed considerable deviation from this trend. The similar change is from the fore gut to the hind gut in all the three sexes during different seasons, it did not give a clear trend of variation in the specimen studied. In general, the total count of pathogenic bacteria was maximum in females followed by indeterminates and males, in different regions of the gut during different seasons ($P < 0.05$, $r = 0.1$ for Mocha and $P < 0.01$, $r = 0.1$ for Dwarka).

The results of the effect of starvation of *P. viridis* on the bacterial percentage of reduction compared to without starvation in *in situ* condition (Tables 4 and 5) are depicted in Tables 6 and 7. The percentage reduction of pathogenic and non pathogenic bacteria at Mocha and Dwarka varied differently in different species. The reduction of total viable count ranged from 47.62% at Dwarka to 70.97% at Mocha, while total coliform varied from 46.07% at Dwarka to 61.21% at Mocha. Similarly, the percentage reduction of *E. coli* ranged from 33.35% at Mocha to 74.07% at Dwarka; however, it was 33.83% at Dwarka to 73.48% again at Dwarka for *Shigella*. The

Table 4. Variation of pathogenic and nonpathogenic bacterial composition of the gut in different sexes of *P. viridis* in *in situ* condition at Mocha (no. × 10^5 g^{-1})

	Male			Female			Indeterminate				
Bacteria	fg	mg	hg	fg	mg	hg	fg	mg	hg	Sea water (no. ml^{-1})	Sediment (no. g^{-1} d.wt)
May											
Total viable count	8.218	9.403	12.536	16.473	16.756	15.523	14.978	16.452	16.725	495.06	523.15
Total coliforms	0.740	0.851	1.105	1.655	1.822	1.992	1.519	1.611	1.645	61.56	68.92
Escherichia coli	0.567	0.569	0.706	0.834	1.058	1.078	0.732	0.890	1.086	2.96	3.04
Shigella	0.612	0.598	0.754	0.915	1.047	1.052	0.806	0.871	1.048	ND	2.56
Salmonella	0.764	0.703	0.865	1.413	1.724	1.520	1.086	1.347	1.188	2.01	3.58
Proteus/ Klebsiella	0.512	0.535	0.786	1.049	1.110	1.104	0.772	0.829	0.946	1.91	2.06
Vibrio cholerae	0.602	0.619	0.869	0.995	1.145	1.078	0.806	0.938	0.978	2.02	2.95
Vibrio parahaemolyticus	0.703	0.682	0.906	1.130	1.163	1.211	1.146	1.202	1.188	2.96	3.25
Other *Vibrios*	0.516	0.577	0.670	0.740	0.879	0.821	0.698	0.701	0.704	ND	2.10
Pseudomonas aeruginosa	0.698	0.774	0.994	1.265	1.377	1.591	0.986	1.274	1.446	1.45	1.96
Streptococcus faecalis	0.941	0.921	1.244	1.917	1.880	1.905	1.519	1.574	1.694	2.06	3.15
Total count of pathogenic bacteria	5.915	5.978	7.794	10.258	11.406	11.360	8.551	9.624	10.278	15.37	24.65
August											
Total viable count	11.201	13.141	14.346	16.674	16.536	18.614	16.485	16.622	17.794	546.21	601.85
Total coliforms	1.365	1.207	1.282	2.016	2.135	2.151	1.819	1.755	1.815	60.21	65.86
Escherichia coli	0.673	0.775	0.857	1.052	1.065	1.085	0.928	0.996	1.057	3.35	4.01
Shigella	0.754	0.817	0.892	1.037	1.044	1.041	0.865	0.968	0.915	3.26	4.13
Salmonella	1.002	1.032	1.108	1.725	1.572	1.533	1.247	1.392	1.463	3.42	4.02
Proteus/Klebsiella	0.658	0.803	0.900	1.203	1.024	1.148	1.068	1.024	1.042	2.15	3.09
Vibrio cholerae	0.802	0.908	0.974	1.264	1.227	1.297	1.119	1.137	1.242	2.86	3.06
Vibrio parahaemolyticus	0.816	0.922	0.987	1.215	1.197	1.278	1.132	1.222	1.294	3.95	4.52
Other *Vibrios*	0.773	0.784	0.805	0.939	0.902	0.979	0.948	0.883	1.009	3.16	4.98
Pseudomonas aeruginosa	0.945	1.138	1.264	1.442	1.526	1.668	1.177	1.619	1.684	2.02	3.96
Streptococcus faecalis	1.604	1.660	1.785	1.778	1.800	1.890	1.641	1.755	1.815	3.06	3.76
Total count of pathogenic bacteria	8.027	8.839	9.572	11.655	11.357	11.919	10.125	10.996	11.521	27.23	31.67
November											
Total viable count	15.111	16.875	20.134	19.989	20.314	22.833	17.764	20.312	20.584	763.41	771.91
Total coliforms	1.493	1.420	1.756	2.088	2.245	2.289	1.945	2.014	2.077	71.23	85.86
Escherichia coli	0.790	0.843	1.051	1.111	1.101	1.191	0.961	0.988	1.051	4.26	4.91
Shigella	0.784	0.832	1.027	1.367	1.336	1.398	0.920	1.292	1.206	5.43	6.21
Salmonella	1.060	1.214	1.452	1.682	1.708	1.784	1.326	1.547	1.552	4.63	5.12
Proteus/Klebsiella	0.951	1.125	1.213	1.324	1.211	1.212	0.972	1.335	1.236	2.98	3.16
Vibrio cholerae	1.465	1.245	1.540	1.330	1.499	1.678	1.337	1.509	1.492	3.02	3.85
Vibrio parahaemolyticus	1.572	1.219	1.653	1.340	1.438	1.521	1.079	1.346	1.432	4.23	5.96
Other *Vibrios*	0.883	0.865	1.037	1.148	1.044	1.085	1.073	1.097	1.061	3.62	4.02
Pseudomonas aeruginosa	1.120	1.354	1.589	1.607	1.708	1.784	1.450	1.596	1.732	1.05	1.96
Streptococcus faecalis	1.139	1.402	1.741	1.875	1.722	1.954	1.607	1.742	1.797	2.45	3.06
Total count of pathogenic bacteria	9.614	10.099	12.003	12.784	12.709	13.607	10.552	12.452	12.559	31.67	38.25

fg, fore gut; mg, mid gut; hg, hind gut.

reduction of *Salmonella* ranged from 39.04% at Dwarka to 66.45% at Mocha, while for *Vibrio cholerae*, it varied from 42.81% at Mocha to 63.16% at Dwarka. Similarly, *Vibrio parahaemolyticus* showed the reduction of 35.03% at Dwarka to 64.72% again at Dwarka, while 28.92% at Dwarka to 71.25% reduction at Mocha was observed for other *Vibrio* species. The percentage reduction of *Pseudomonas aeruginosa* ranged from 37.03% at Mocha to 75.25% at Dwarka, while for *Streptococcus faecalis*, it varied from 39.43% at Mocha to 61.59% again at Mocha. At Mocha, *Proteus*/*Klebsiella* showed increase in some parts of gut in all three months after starvation. The reduction of different species of bacteria in different sexes, different regions of the gut and different seasons did not show any definite trend of variation, both at Mocha and Dwarka.

The accumulation of high concentration of metals in the green mussel depends on the relative concentration of these metals in the surrounding waters[34,35]. The metal level in the molluscan species usually varied with size, sex, feeding habits, reproductive conditions, seasons and extent of pollution in the ambient medium[36,37]. The pollution of coastal waters by heavy metals poses a big problem due to their toxicity and accumulation by marine

Table 5. Variation of pathogenic and nonpathogenic bacterial composition of the gut in different sexes of *P. viridis* in *in situ* condition at Dwarka (no. × 10^5 g^{-1})

	Male			Female			Indeterminate				
Bacteria	fg	mg	hg	fg	mg	hg	fg	mg	hg	Sea water (no. ml^{-1})	Sediment (no. g^{-1} d.wt)
May											
Total viable count	15.422	16.528	21.839	27.846	27.854	28.036	23.718	24.516	25.188	1096.23	9896.06
Total coliforms	1.779	1.323	1.709	3.157	3.442	3.607	2.873	2.883	2.839	106.06	119.68
Escherichia coli	0.907	0.873	1.321	1.481	1.608	1.630	1.229	1.462	1.624	7.23	7.96
Shigella	0.946	0.946	1.308	1.508	1.446	1.523	1.392	1.480	1.433	5.61	6.10
Salmonella	1.065	0.941	1.258	2.357	2.383	2.383	1.670	2.295	2.169	3.66	4.21
Proteus/Klebsiella	0.753	0.840	1.406	1.690	1.695	1.736	1.263	1.272	1.689	4.62	5.16
Vibrio cholerae	0.907	1.056	1.196	1.641	1.677	1.699	1.453	1.641	1.613	2.16	3.00
Vibrio parahaemolyticus	1.065	0.899	1.468	1.886	1.822	2.030	1.996	1.748	2.234	4.62	5.81
Other *Vibrios*	0.971	0.746	0.861	1.187	1.232	1.683	1.236	1.082	1.079	5.61	6.82
Pseudomonas aeruginosa	0.922	0.912	1.633	2.200	2.447	2.971	1.698	1.486	2.441	2.02	2.75
Streptococcus faecalis	1.477	1.484	1.852	3.087	3.014	3.340	2.621	2.295	2.812	2.85	3.01
Total count of pathogenic bacteria	11.857	7.697	12.303	17.055	17.323	18.995	14.588	14.761	17.094	38.37	44.82
August											
Total viable count	20.350	21.453	24.262	29.844	30.326	31.247	27.078	29.437	27.535	1249.60	10891.02
Total coliforms	2.341	2.275	2.270	4.180	3.988	3.970	3.196	3.154	3.877	121.21	129.62
Escherichia coli	1.042	1.348	1.318	1.659	1.677	1.558	1.541	1.792	1.594	8.42	9.16
Shigella	1.172	1.186	1.314	1.503	1.533	1.548	1.410	1.568	1.672	7.21	9.23
Salmonella	1.858	1.849	1.816	2.496	2.290	2.580	2.444	2.378	2.510	4.61	6.36
Proteus/Klebsiella	0.955	1.140	1.270	1.594	1.621	1.846	1.447	1.758	1.635	5.02	6.00
Vibrio cholerae	1.148	1.459	1.576	2.105	2.120	2.064	1.974	2.160	2.049	3.91	4.06
Vibrio parahaemolyticus	1.428	1.510	1.685	1.864	2.038	2.084	1.880	1.999	2.127	6.23	7.63
Other *Vibrios*	1.197	1.218	1.205	1.383	1.441	1.439	1.384	1.430	1.475	7.49	7.88
Pseudomonas aeruginosa	1.515	2.080	2.113	2.496	3.016	3.037	2.594	2.999	3.033	2.11	2.82
Streptococcus faecalis	2.104	2.382	2.589	3.278	3.345	3.304	3.271	3.367	3.214	3.13	4.06
Total count of pathogenic bacteria	12.419	14.172	14.886	18.378	19.089	19.460	17.945	19.451	19.309	48.13	57.20
November											
Total viable count	26.129	25.094	28.122	34.487	36.189	40.573	29.253	31.608	30.519	1486.91	11846.38
Total coliforms	2.509	2.588	3.256	3.852	4.117	4.059	3.480	3.476	3.927	128.62	143.56
Escherichia coli	1.337	1.451	1.724	1.645	1.775	2.041	1.597	1.690	1.855	10.98	11.42
Shigella	1.204	1.552	1.825	2.185	2.236	2.432	1.154	2.151	1.500	8.46	10.61
Salmonella	1.850	2.068	2.502	2.762	3.139	3.260	2.385	2.661	2.580	6.98	7.81
Proteus/Klebsiella	1.447	1.602	1.662	1.699	1.899	1.877	1.543	1.715	1.954	5.43	6.21
Vibrio cholerae	1.912	2.022	2.363	2.962	2.766	3.161	2.171	2.554	2.595	4.21	5.03
Vibrio parahaemolyticus	1.884	2.039	2.786	2.239	2.734	2.807	2.099	2.366	3.113	7.52	8.26
Other *Vibrios*	1.296	1.338	1.345	1.699	1.475	1.543	1.683	1.620	1.500	8.41	9.86
Pseudomonas aeruginosa	1.907	2.458	2.848	2.962	3.139	3.260	2.422	2.763	3.197	2.61	3.85
Streptococcus faecalis	1.907	2.437	2.983	2.806	2.932	3.511	2.660	3.171	3.345	3.91	4.26
Total count of pathogenic bacteria	14.744	16.967	20.038	20.959	22.095	23.892	17.619	20.691	21.639	58.51	67.31

fg, fore gut; mg, mid gut; hg, hind gut.

organisms[17]. The results in the present study indicate that the concentration of the nine heavy metals studied was always higher in the soft tissue, especially in the gonad compared to ambient sea water. Similar results have been observed by several authors[7–12,38–39].

A high concentration of heavy metals in *P. viridis* has been reported during monsoon and a minimum during summer[7,8,10,40,41]. Similar results have been observed in the present study, when animals were collected during monsoon (August) and summer (May). Since the highest and lowest accumulation of heavy metals was observed in August and May respectively and highest soft tissue weight in November, therefore, it is advisable that this species may be suitable for human consumption during May and November. *P. viridis* has shown very high magnitude of accumulation of Fe in its tissue (230.58 to 618.25 μg g^{-1}). Similar results have been observed by Bhosle and Matondkar[9] and Lakshmanan and Nambisan[10]. Therefore this organism can be a very good natural source of iron for anaemic patients. It is important to note that this organism is eaten by the coastal population of peninsular India[1–3].

A strong positive correlation ($r = 0.1$) has been observed between carotenoid (total and unsaponifiable) and heavy metals in *P. viridis* ($P < 0.05$, $r = 0.1$ for Mocha and $P < 0.01$, $r = 0.1$ for Dwarka). The present study indicates that the concentration of carotenoids was high when heavy metal concentration was high in the tissues. It has been reported that concentrations in *P. viridis* are directly related to heavy metal concentrations in sea water[27]. In the present study, when the concentration of heavy metals was the highest in sea water, the carotenoid content was also the highest. Molluscs having high carotenoid content are strongly resistant to environmental pollution[27]. The close correlation between the tolerance of the molluscs to environ-

Table 6. Percentage increase/decrease of bacteria in the gut of *P. viridis* at Mocha after 5 days of starvation

	Male				Female				Indeterminate			
Bacteria	fg	mg	hg	% mean	fg	mg	hg	% mean	fg	mg	hg	% mean
May												
Total viable count	68.42	70.03	59.21	65.88	47.65	57.25	73.96	59.62	41.68	45.96	56.83	48.15
Total coliforms	56.08	60.40	67.15	61.21	45.07	48.07	57.27	50.13	47.26	54.69	58.54	53.49
Escherichia coli	34.92	44.99	43.63	41.18	57.19	55.29	57.14	56.54	44.39	44.49	38.12	42.33
Shigella	50.00	57.19	57.16	54.78	56.39	54.63	64.73	58.58	39.20	58.78	56.87	51.61
Salmonella	52.09	67.28	65.09	61.48	49.25	40.77	58.94	49.65	44.38	43.95	60.44	49.59
Proteus/Klebsiella	94.34	9.71^{+}	8.02^{+}		62.53	79.81	18.84^{+}		80.69	86.24	96.51	87.81
Vibrio cholerae	57.81	64.14	51.21	57.72	41.39	43.31	57.14	47.28	39.21	42.86	57.57	46.54
Vibrio parahaemolyticus	47.08	58.50	56.50	54.03	42.12	51.24	62.35	51.90	28.18	48.67	55.72	44.19
Other *Vibrios*	60.46	78.51	74.78	71.25	57.43	54.37	62.85	58.21	30.94	51.78	65.76	49.49
Pseudomonas aeruginosa	50.43	48.58	50.50	49.83	39.36	40.88	47.45	42.56	41.40	40.18	47.65	43.07
Streptococcus faecalis	33.26	44.73	40.32	39.43	40.58	43.40	48.08	44.02	38.58	43.32	47.99	43.29
August												
Total viable count	63.73	62.35	66.12	64.06	63.47	76.31	73.13	70.97	52.11	58.25	59.48	56.61
Total coliforms	33.77	47.88	59.12	41.92	47.77	55.36	66.75	56.62	48.15	53.90	64.07	55.37
Escherichia coli	30.75	38.45	36.87	35.35	54.94	57.84	68.75	60.51	40.73	41.36	40.30	40.79
Shigella	46.02	56.05	64.12	55.39	56.03	59.19	69.74	61.65	52.25	62.08	67.21	60.51
Salmonella	45.20	54.36	55.32	51.62	41.16	54.83	66.60	54.19	43.46	49.78	65.07	52.77
Proteus/Klebsiella	78.41	91.65	32.44^{+}		78.63	79.58	15.50^{+}		67.04	11.52^{+}	24.56^{+}	
Vibrio cholerae	44.13	44.27	53.11	47.17	37.89	42.05	60.52	46.82	35.56	43.62	49.27	42.81
Vibrio parahaemolyticus	42.52	45.11	59.37	49.00	43.04	56.97	65.88	55.29	43.81	49.91	57.10	50.27
Other *Vibrios*	59.50	23.59	36.27	39.78	52.82	55.54	57.50	52.28	26.68	54.92	50.04	43.88
Pseudomonas aeruginosa	39.68	36.55	43.98	40.07	38.90	44.10	50.53	44.51	29.73	37.30	44.06	37.03
Streptococcus faecalis	29.17	32.71	34.17	32.01	48.14	54.72	57.40	53.42	37.47	52.30	50.83	46.86
November												
Total viable count	62.76	62.89	63.14	62.93	62.15	67.02	72.18	67.11	60.92	62.10	62.73	61.91
Total coliforms	64.03	68.45	48.17	60.21	55.74	60.75	66.53	60.94	54.08	60.47	63.31	59.28
Escherichia coli	67.59	70.22	36.63	58.14	61.56	65.03	70.78	65.79	54.00	62.34	56.89	57.74
Shigella	69.64	79.44	69.71	72.93	54.79	63.77	65.30	61.28	66.95	50.23	64.92	60.70
Salmonella	68.01	66.47	64.87	66.45	47.85	59.72	65.19	56.92	56.41	48.67	57.73	54.27
Proteus/Klebsiella	79.39	73.33	77.98	76.90	94.48	30.71^{+}	98.10		81.27	3.52^{+}	13.75^{+}	
Vibrio cholerae	42.66	58.07	59.28	53.33	54.74	54.76	54.58	55.69	51.24	49.96	56.63	52.61
Vibrio parahaemolyticus	43.70	57.58	49.36	50.21	52.31	50.00	64.76	55.69	66.54	54.60	59.21	60.11
Other *Vibrios*	50.39	59.19	59.40	56.32	42.24	57.66	63.87	54.59	29.63	53.32	59.94	47.63
Pseudomonas aeruginosa	58.21	48.96	54.18	53.78	47.49	53.57	55.77	52.37	49.35	51.56	54.38	51.76
Streptococcus faecalis	63.74	54.27	54.68	57.56	52.05	67.59	65.14	61.59	53.08	44.83	58.76	52.22

fg, fore gut; mg, mid gut; hg, hind gut.

Table 7. Percentage increase/decrease of bacteria in the gut of *P. viridis* at Dwarka after 5 days of starvation

	Male				Female				Indeterminate			
Bacteria	fg	mg	hg	% mean	fg	mg	hg	% mean	fg	mg	hg	% mean
May												
Total viable count	52.23	60.62	51.33	54.72	41.51	46.74	54.63	47.62	44.78	45.70	51.69	47.39
Total coliforms	44.18	73.18	4.27^{+}		41.68	44.91	51.64	46.07	41.69	54.21	63.86	53.25
Escherichia coli	21.83	45.01	47.00	36.94	31.26	43.28	53.01	42.51	37.59	35.77	49.13	40.83
Shigella	31.92	40.38	29.20	33.83	45.15	56.43	78.33	59.97	71.83	34.59	48.70	51.70
Salmonella	49.95	76.30	57.07	61.10	22.86	41.33	52.95	39.04	32.27	35.38	49.97	39.20
Proteus/Klebsiella	32.93	49.16	47.15	43.08	34.67	42.24	66.12	47.67	28.58	45.75	45.29	40.54
Vibrio cholerae	60.41	58.33	60.53	59.65	43.57	63.38	75.69	60.88	35.71	37.65	58.40	43.92
Vibrio parahaemolyticus	26.10	43.93	35.08	35.03	32.76	44.78	58.37	45.30	41.33	64.58	60.78	55.56
Other *Vibrios*	26.87	28.82	36.23	30.64	26.62	33.92	32.62	31.05	13.18	28.83	44.76	28.92
Pseudomonas aeruginosa	74.07	95.61	56.09	75.25	38.77	47.36	45.50	43.87	24.91	48.11	46.94	39.98
Streptococcus faecalis	53.14	51.45	44.16	49.58	30.51	43.53	46.76	40.26	35.94	50.58	49.64	45.38
August												
Total viable count	56.32	59.91	60.72	58.98	44.12	54.34	58.92	52.46	47.31	53.04	58.77	53.04
Total coliforms	50.79	56.04	58.81	55.21	45.76	54.06	55.86	51.89	50.78	60.65	54.24	55.22
Escherichia coli	50.00	42.58	54.09	48.89	37.25	42.63	58.79	46.22	26.93	34.38	52.92	38.07
Shigella	50.00	50.00	57.53	52.51	54.02	78.01	88.43	73.48	50.92	38.39	44.80	44.70
Salmonella	33.85	38.72	50.00	40.85	45.51	64.89	58.64	56.34	40.13	42.56	47.61	43.43
Proteus/Klebsiella	50.05	50.52	40.79	47.12	51.31	73.59	71.66	65.52	49.97	44.31	57.61	50.63
Vibrio cholerae	62.54	55.72	53.43	57.23	49.97	62.21	77.32	63.16	50.05	42.40	49.98	47.47
Vibrio parahaemolyticus	36.13	46.23	44.63	42.33	46.24	50.00	63.00	53.08	64.52	71.34	76.21	70.69
Other *Vibrios*	41.02	41.30	45.06	42.46	22.77	28.86	43.01	31.54	42.84	36.15	41.69	40.22
Pseudomonas aeruginosa	60.26	52.93	59.06	47.47	47.47	43.96	55.44	48.95	38.28	34.88	42.37	38.51
Streptococcus faecalis	47.53	45.55	45.81	46.29	36.27	42.72	51.93	43.64	45.42	41.83	50.12	45.79
November												
Total viable count	46.47	60.09	61.92	56.16	47.02	53.64	53.88	51.51	46.38	46.24	55.76	49.46
Total coliforms	51.13	52.24	45.55	49.64	56.28	58.68	62.40	59.12	57.04	62.82	58.95	59.60
Escherichia coli	55.50	56.03	53.25	54.92	50.09	53.41	49.98	51.16	72.07	73.43	76.71	74.07
Shigella	70.02	58.83	61.42	63.42	54.59	65.34	62.42	60.78	55.63	39.19	62.33	52.38
Salmonella	60.16	58.80	55.20	58.05	45.11	51.48	56.63	51.07	46.79	46.64	57.48	50.30
Proteus/Klebsiella	44.64	38.14	39.29	40.69	57.98	65.61	75.28	66.29	55.22	53.41	56.66	55.09
Vibrio cholerae	51.41	50.00	54.72	52.04	47.87	54.81	55.24	52.64	50.44	45.14	40.19	45.25
Vibrio parahaemolyticus	43.31	50.12	42.53	45.32	61.86	51.79	60.03	57.89	69.37	65.64	59.17	64.72
Other *Vibrios*	32.10	37.52	38.41	36.01	42.08	54.92	55.93	50.97	36.89	50.92	56.20	48.00
Pseudomonas aeruginosa	44.20	60.41	56.64	53.75	54.56	55.50	58.77	56.27	54.33	41.69	43.32	46.44
Streptococcus faecalis	42.79	49.98	42.51	45.09	50.00	55.18	55.34	53.50	60.00	53.36	54.20	55.85

fg, fore gut; mg, mid gut; hg, hind gut.

ment pollution and the content of carotenoids in their bodies supports the hypothesis that the carotenoids take part in oxygen metabolism of animal cells, providing an intracellular reserve (accumulator) of oxygen (or its electron acceptor equivalent)[26].

The authors are unaware of any work done on the bacterial composition of the gut of *P. viridis* under Indian conditions. However, the composition of different pathogenic and non pathogenic bacteria of mucoidal discharges of *P. viridis* has been studied[30]. This gives an indication of a mixed bacterial flora of gut and stomach. Seki[42] stated that the morphologically different groups of bacteria occurring in the gut region at a given time, primarily depend on the quantum and type of food recently ingested. The microorganisms in the digestive system of aquatic organisms have been implicated to play a significant role in the digestion, metabolism and nutrition of fish and shell fish. The bacterial growth rate and the faster multiplication associated with fish and shell fish are important phenomena for the fast decomposition of organic compounds[43].

1. Wafer, M. V. M., Vijayaraghavan, S. and Krishnakumari, L., *Indian J. Mar. Sci.*, 1976, 252– 254.
2. Pai, M. V. and Kuriakose, P. S., *Mar. Fish. Inf. Ser.*, 1981, **33**, 13–16.
3. Rivonker, C. V. and Parulekar, A. H., *J. Mar. Biol. Assoc. India*, 1995, **37**, 231–233.
4. Tewari, A., Joshi, H. V., Raghunathan, C., Sravan Kumar, V. G. and Kotiwar, O. S., *Curr. Sci.*, 2000, **78**, 97–102.
5. Jones, S., *Mar. Biol. Assoc. India*, 1968, **2**, 906.
6. Qasim, S. Z., Parulekar, A. H., Harkantra, S. N., Ansari, Z. A. and Nair, A., *Indian J. Mar. Sci.*, 1977, **6**, 15–25.
7. Senthilnathan, S. and Balasubramanian, T., *Indian J. Mar. Sci.*, 1998, **27**, 211–216.
8. Senthilnathan, S., Balasubramanian, T. and Venugopalan, V. K., *Indian J. Mar. Sci.*,1998, **27**, 206–210.
9. Bhosle, N. B. and Matondkar, S. G. P., *Mahasagar*, 1978, **11**, 109–194.
10. Lakshmanan, P. T. and Nambisan, P. N. K., *Indian J. Mar. Sci.*, 1983, **12**, 100–103.

11. Rivonker, C. V. and Parulekar, A. H., *Indian J. Mar. Sci.*, 1998, **27**, 411–415.
12. Krishnakumar, P. K., Bhatt, G. S., Vaidya, N. G. and Pillai, V. K., *Indian J. Mar. Sci.*, 1998, **27**, 201–205.
13. Phillips, D. J. H., *Mar. Ecol. Prog. Ser.*, 1985, **21**, 251–258.
14. Phillips, D. J. H. and Muttarasin, K., *Mar. Environ. Res.*,1985, **15**, 215–234.
15. Chan, H. M., *Mar. Ecol. Prog. Ser.*, 1988, **48**, 295–303.
16. Haynes, D. and Toohey, D., *Mar. Pollut. Bull.*, 1995, **30**, 885–891.
17. Rainbow, P. S., *Mar. Pollut. Bull.*, 1995, **31**, 183–192.
18. Phillips, D. J. H., *Mar. Biol.*, 1976, **38**, 59–69.
19. Phillips, D. J. H., *Mar. Biol.*, 1977, **43**, 283–291.
20. Phillips, D. J. H., *Mar. Biol.*, 1978, **46**, 147–156.
21. Bryan, G. W., Langston, W. J. and Hummerstone, L. G., *Mar. Biol. Assoc. UK*, 1980, 1–73.
22. Klumpp, D. W. and Burdon-Jones, C., *Aust. J. Mar. Freshwater Res.*, 1982, **33**, 285–300.
23. Phillips, D. J. H. and Yim, W., *Mar. Ecol. Prog. Ser.*, 1981, **6**, 285–293.
24. Prest, H. F., Richardson, B. J., Jacobson, L. A., Vedder, J. and Martin, M., *Mar. Pollut. Bull.*, 1995, **30**, 543–554.
25. Haynes, D. and Toohey, D., *Mar. Pollut. Bull.*, 1998, **36**, 396–399.
26. Karnaukhov, V. N., Milondova, N. Y. and Kargopolova, I. M., *Comp. Biochem. Physiol.*,1977, **56**, 189–193.
27. Krishnakumar, P. K., Damodaran. R. and Nambisan, P. N. K., *Indian J. Mar. Sci.*, 1987, **16**, 155–157.
28. Mathew, S. and Damodaran, R., *Indian J. Mar. Sci.*,1997, **26**, 57–63.
29. Rajagopalan, K. and Sivalingam, P. M., *Malays. J. Appl. Biol.*, 1978, **7**, 43.
30. Sivalingam, P. M. and Rajagopalan, K. *Indian J. Mar. Sci.*, 1981, **10**, 98–100.
31. Annual Report, Central Salt and Marine Chemicals Research Institute, Bhavnagar, table 233, figure 32, 2000, p. 197.
32. Ruiz, G. M., Rawlings, T. K., Dobbs, F. C., Drake, L. A., Mullady, T., Huq, A. and Colwell, R. R, *Nature*, 2000, **408**, 49–50.
33. Tewari, A. *et al.*, *Mar. Pollut. Bull.*, 2001, **42**, 461–468.
34. Boyden, C. R. and Romeril, M. G., *Mar. Pollut. Bull.* 1974, **5**, 74–78.
35. Martincic, Y., Nurnberg, H. W. and Branica, M., *Mar. Chem.*, 1986, **18**, 299.
36. Eisler, R., Narry, M. M., Lapan, R. L., Relex, G., Daway, E. W. and Soper, A. E., *Mar. Biol.*, 1978, **45**, 311.
37. Pillai, V. K. and Valsala, K. K., *Indian J. Mar. Sci.*, 1995, **24**, 113.
38. Richardson, B. J., Garnham, J. S. and Fabris, J. G., *Mar. Pollut. Bull.*, 1994, **28**, 392–396.
39. Manly, R., Blundell, S. P., Fifield, F. W. and McCabe, P. J., *Mar. Pollut. Bull.*, 1996, **32**, 444–448.
40. Farrington, J. W., Goldberg, E. D., Risebrough, R. W., Martin, J. H. and Bawen, V. T., *Environ. Sci. Technol.*, 1983, **17**, 490.
41. Amiard, J. C., Amiard-Triquet, C., Nerthet, B. and Metayer, C., *Mar. Biol.*, 1986, **19**, 425.
42. Seki, M. J., *Appl. Microbiol.*, 1969, **17**, 252.
43. Maya, R., Dhevendaran, Annie Mathew, Georgekutty, M. I. and Natarajan, P., *Indian J. Mar. Biol.*, 1995, **24**, 225–228.

ACKNOWLEDGEMENTS. We thank Dr P. K. Ghosh, Director, Central Salt and Marine Chemicals Research Institute, Bhavnagar, for his encouragement and for providing laboratory facilities. Sincere thanks are also due to Dr B. K. Ramavat for help during collection and Mr A. M. Shah for help during statistical analysis. Financial support provided by the Department of Ocean Development, Government of India is gratefully acknowledged.

Received 8 March 2001; revised accepted 6 June 2001

Submerged beach ridge lineation and associated sedentary fauna in the innershelf of Gopalpur coast, Orissa, Bay of Bengal

K. Mohana Rao*, K. S. R. Murthy, N. P. C. Reddy, A. S. Subrahmanyam, S. Lakshminarayana, M. M. M. Rao, K. V. L. N. S. Sarma, M. K. Premkumar, A. Sree[†] and M. Bapuji[†]

National Institute of Oceanography, Regional Centre, 176, Lawsons Bay, Visakhapatnam 530 017, India
[†]Regional Research Laboratory, Bhubaneswar 751 013, India

Detailed echosounding and side-scan sonar surveys coupled with SCUBA-diving operations in the inner-shelf region of Gopalpur, Orissa coast revealed the existence of a submerged NE-SW trending ridge lineation between the isobaths of 25 and 35 m. Morphology of this ridge indicates parallel to sub-parallel pinnacles with variable relief and widths. Very steep scarps in the leeward side of the seabed at many places are attributed to large-scale seabed scouring. Diving operations recovered extensive live sedentary fauna such as sponges, gorgonians, soft and hard corals along with rock encrustations from the ridge features. X-ray diffraction analysis of the rock samples revealed the mineral composition of quartz, feldspars, and low and high magnesium calcite, suggesting the morphological features to be of beach sandstone formation. High-resolution shallow seismic records indicate that the features are from the hard subsurface reflector, probably of Late Pleistocene. The composition of sedentary fauna is discussed and its association over the features is attributed to the availability of porous beach sandstone which favours growth in euphotic zone.

THE continental shelf of Gopalpur coast, Orissa had been earlier studied by several workers in different aspects of relict morphological features related to Late Quaternary sea-level variations, sedimentology and mineralogy[1–9]. These studies indicated the presence of topographic highs, palaeo channels, relict sediments, etc. and attributed them to the low stand phases of the sea at different water depths of 20–30, 50–60 and 100 m, due to sea-level oscillations during Late Pleistocene–Holocene. Under a collaborative programme between Regional Research Laboratory, Bhubaneswar and Regional Centre of National Institute of Oceanography, Visakhapatnam for collection of marine organisms off Orissa coast under the DOD funded project, Potential drugs from sea, a number of sedentary fauna were collected from submerged rocks off Gopalpur coast during several occasions of underway investigations comprising echo-sounding, side-scan sonar and shallow seis-

*For correspondence. (e-mail: kmrao@kadali.nio.org)