

Effects of turbidity on survival, osmoregulation and gill $\text{Na}^+\text{-K}^+$ ATPase in juvenile shrimp *Penaeus japonicus*

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ABSTRACT: *Penaeus japonicus* juveniles were exposed for 3 wk to different turbidities of suspended sediments: control [2 ± 2 nephelometric turbidity units (NTU)], medium turbidity (35 ± 15 NTU) and high turbidity (65 ± 15 NTU). The mortality rate increased after exposure to high turbidity. Exposed late juveniles became less tolerant to changes in ambient salinity and showed higher mortalities at low salinity. The effect on osmoregulatory capacity of shrimps was examined by determining the osmotic gradient between the haemolymph and the external medium in concentrated seawater (42‰ S) and in dilute seawater (15‰ S). In young juveniles, osmoregulatory capacity was generally not affected by turbidity. In late juveniles, it was significantly reduced by turbidity. Reduced osmoregulatory capacity resulted from impaired regulation of Na^+ and Cl^- concentrations. Gill $\text{Na}^+\text{-K}^+$ ATPase activity of exposed late juveniles increased with turbidity, apparently as a compensating reaction to the disruption of osmotic and ionic balance.

INTRODUCTION

Turbidity originating from suspended sediments is one of the least-studied aquatic factors, although it is frequently encountered in natural environments. High levels of suspended sediments could result from increasing discharge and environmental disturbance, such as heavy rainfall carrying large amounts of topsoil to the water and strong winds violently stirring coastal water. Turbidity can vary from less than 0.1 nephelometric turbidity units (NTU) in off-shore ocean to several hundred NTU in estuaries (Aminot 1983). Servizi & Martens (1987) have recorded levels of suspended solids ($>600 \text{ mg l}^{-1}$) which resulted in a stress response in sockeye salmon *Oncorhynchus nerka* during spawning migration in the Fraser River, British Columbia. Increase in suspended sediments may cause indirect effect by changing plant communities and living habitat (reducing light penetration to water, increasing sediment deposition), and can directly affect the physiology and behaviour of individual species (Lively et al. 1983, Lloyd 1987).

There is little information available on the physiological effects of turbidity. Previous studies have demonstrated that high turbidity may impair reproduction and osmoregulation, reduce the exchange rate of O_2 and alter respiration in molluscs and fish (Widdows et al. 1979, Servizi & Martens 1987, Daou & Gouletquer 1988). Studies cited by Servizi & Martens (1991) suggest that reduced oxygen uptake or exchange is a major factor causing mortality in exposed fish. To our knowledge, no study concerning the effect of turbidity has been reported for crustaceans. Penaeid shrimps at juvenile and adult stages, which are benthic and in some species spend long periods buried in sediments, are more frequently exposed to high turbidity than pelagic or planktonic species. Water currents may stir up fine particles, faeces and pseudofaeces, causing a zone of high turbidity near the bottom even though the water is clear at the surface (Rhoads 1974). With the trend toward intensification of pond culture, aerators have become more widely utilized (Sandifer et al. 1988, Wyban et al. 1989). Aeration, especially in earthen ponds, can stir up bottom sediments and dramatically enhance water turbidity (Lin pers. obs.).

Hopkins et al. (1988) found that the level of suspended solids in aerated *Penaeus vannamei* ponds is consistently higher than that of the inlet water, but that it is not significantly affected by stocking density ranging from 20 to 60 shrimps m^{-2} . Another artificial disturbance – digging and pushing, a common behavior of most penaeid species – also significantly increases turbidity at the pond bottom. Buried in this turbid zone, penaeid shrimps still require a regular water current from an external medium to flush the gill chamber (Dall et al. 1990). There were indications in our field studies that *Penaeus japonicus* juveniles grown in marsh-earth ponds might be adversely affected by suspended sediments; low growth rate and high mortality, especially for late juveniles, were apparently related to the occurrence of high turbidity (Lin & Hatt unpubl.).

In penaeids, gills are the principal site of respiration and play an essential role in the control of ion and water balance, thus contributing to the maintenance of the organisms' physiological condition. We demonstrated in previous studies that the ability to osmoregulate, evaluated by the osmoregulatory capacity (OC), can be used as an indicator of physiological condition in crustaceans (Charmantier et al. 1989); environmental stresses, for example sublethal ambient ammonia, depressed OC partially or completely in *Penaeus japonicus* and *Homarus americanus* (Lin et al. 1991, Young-Lai et al. 1991). In this study, OC was used to evaluate the physiological effect of turbidity in young and late *P. japonicus* juveniles. Additionally, Na^+ and Cl^- regulation and gill Na^+-K^+ ATPase activity were also determined, since Na^+ and Cl^- are principally responsible for the osmotic pressure of the haemolymph (Potts & Parry 1964) and Na^+-K^+ ATPase plays an essential role in active ion transport (Towle 1984, 1990).

MATERIALS AND METHODS

Shrimp and exposure media. This study was conducted in July 1990 using young *Penaeus japonicus* juveniles (2.0 ± 0.6 g) obtained from Aqualive, an aquacultural station of IFREMER in Noirmoutier, Vendée (France), and then in October of the same year using late juveniles (9.7 ± 1.3 g) from Mari Aude S.A., a Mediterranean shrimp farm in Port-Leucate, Aude. In the first experiment conducted at the station, young juveniles collected from ponds were directly used for tests. In the second experiment in our laboratory, late juveniles, after 2 h of transport from the field, were acclimated in concrete tanks for at least 10 d. Each tank held 4000 l of filtered recirculated sea water (Eheim system) at 36 ‰ S and 20 °C. The photoperiod was 12L/12D and food consisted of frozen mussels.

Nephelometric turbidity units and the concentration of suspended material are used to measure different characteristics of turbid media. For a given medium, there is an approximate correlation between the 2 parameters (Aminot 1983). Servizi & Gordon (1989) established a linear regression ($R = 0.9$) between turbidity and suspended solids measured in the Fraser River at Hell's Gate. In the present experiment, the turbid condition of exposure media was expressed by turbidity units. The control medium was set at 2 ± 2 NTU; 2 exposure media were maintained at medium turbidity, MT (35 ± 15 NTU), and high turbidity, HT (65 ± 15 NTU), respectively. The turbid media were prepared with dried sediment collected from a shrimp pond in Noirmoutier. The composition of sediment, determined according to Aminot (1983), was 30.1 % clay (size of particles < 0.002 mm), 33.4 % silt (0.002 to 0.05 mm), 30.9 % fine sand (0.05 to 0.2 mm) and 5.6 % coarse sand (0.2 to 2.0 mm). The desired turbidities were obtained by adding corresponding amounts of dried sediment to sea water. Each medium was well stirred by fine air bubbles from long ceramic air-bubblers and sediment particles remained constantly in suspension.

For the survival assays, 15 acclimated shrimps were placed in a tank containing 45 l of each medium. Control and turbid media were all duplicated. During 3 wk of exposure, half the volume of each medium was renewed every other day. Turbidity was measured with a HACH 2100 turbidimeter and monitored twice a week. The concentration of suspended inorganic materials was determined at the beginning of each exposure test according to Aminot (1983); pH and salinity were both monitored daily. The concentration of dissolved oxygen in the media was maintained above 5 mg l^{-1} throughout the experiment.

Osmoregulatory capacity, Na^+ and Cl^- regulation. Osmoregulatory capacity (mosm kg^{-1}) is defined as the osmotic gradient between the haemolymph and the external medium at a given salinity. Since most penaeid shrimps are hypo-hyper-regulators (review in Charmantier 1987), the effect of turbidity on young and late *Penaeus japonicus* juveniles was evaluated by determining the hypo-OC at $1200 \pm 10 \text{ mosm kg}^{-1}$ (42 ‰ S) and the hyper-OC at $450 \pm 10 \text{ mosm kg}^{-1}$ (15 ‰ S), after 3 wk of exposure. Na^+ and Cl^- regulation in late juveniles, i.e. the ionic gradients between the haemolymph and the external medium (ΔNa^+ and $\Delta Cl^- \text{ mEq l}^{-1}$), were also measured at those 2 salinities. For this purpose, shrimps after 3 wk exposure to turbidities in full-strength sea water, were transferred to a closed recirculating sea water system in which salinity was gradually increased to 42 ‰ over 24 h by adding Instant Ocean salts. After an additional 24 h for stabilizing haemolymph concentrations, hypo-OC, ΔNa^+

and ΔCl^- were determined. At the same time, other exposed shrimp were placed in the second recirculating system in which sea water was progressively diluted to 15 ‰ S by the addition of tap water over 36 h. Forty-eight hours after the end of dilution, hyper-OC, ΔNa^+ and ΔCl^- were measured.

Since haemolymph concentrations fluctuate with moult stage, only shrimp at moult stage C or D₀ were sampled for the measurements. Moulting stages were determined by microscopic examination of a pleopod according to Drach & Tchernigovtzeff's method (1967). Haemolymph was collected by inserting a syringe into the posterior part of the abdomen. Osmotic pressure was measured on a Wescor 5500 vapor pressure osmometer. Na^+ and Cl^- concentrations were determined with an Eppendorf flame photometer and a Cotlew chloride titrator respectively.

Gill $\text{Na}^+\text{-K}^+$ ATPase activity. Gill $\text{Na}^+\text{-K}^+$ ATPase activity in late juveniles was determined according to the modified technique described by Piper & Lowell (1981) and Zaugg (1982). Immediately after haemolymph sampling, the posterior 8 pairs of gill lamellae on both sides of the cephalothorax were quickly excised and homogenized in Tris-EDTA buffer, pH 7.5 (250 mM sucrose, 20 mM Tris, 2 mM EDTA- Na_2 , 0.1 % Na-deoxycholate), at 4 °C. Gill homogenate was first centrifuged at $800 \times g$ for 25 min at 4 °C. The supernatant was spun at $2500 \times g$ for 25 min at 4 °C. The supernatant from this centrifugation was used for the enzymatic assay. The composition of the reaction medium was: 100 mM Tris buffer, 100 mM Na^+ , 7.5 mM Mg^{++} , 5 mM ATP and 0.5 mM EGTA (ethyleneglycol tetraacetic acid), at pH 7.25. Incubation was conducted at 37 °C and lasted for 30 min. Preliminary experiments had shown that the enzymatic activity was maximum under these conditions. $\text{Na}^+\text{-K}^+$ ATPase activity was determined by comparing the inorganic phosphate between 2 media, with or without the addition of 1 mM ouabain (a specific inhibitor of $\text{Na}^+\text{-K}^+$ ATPase) and 20 mM NH_4^+ . Protein concentrations were determined using bicinchoninic acid (BCA) based on the colorimetric reaction between proteins and Cu^{++} (Smith et al. 1985). $\text{Na}^+\text{-K}^+$ ATPase activity was calculated as $\mu\text{mol P}_i \text{ mg}^{-1} \text{ protein h}^{-1}$.

Experimental data were analysed with ANOVA and Student *t*-tests.

RESULTS

The average concentrations of suspended inorganic materials in control (2 ± 2 NTU), MT (35 ± 15 NTU) and HT (65 ± 15 NTU) media were respectively 18, 152 and 910 mg l^{-1} for young juveniles and 21, 134 and 952 mg l^{-1} for late juveniles. Shrimp exposed to

MT and HT displayed reduced feeding activity. After 3 wk of exposure, the gill chamber (in particular gill lamellae) of MT and HT shrimp became brown-gray and were densely covered with suspended particles. A thick layer of mucous secretion was observed around the gills.

Mortality rates of young and late juveniles exposed to turbidities in seawater (SW; 36 ‰ S) for 3 wk, and after subsequent exposure to concentrated SW (42 ‰) or dilute SW (15 ‰), are given in Table 1. In young juveniles, only HT caused a slightly higher mortality (15 %) than the control turbidity (7 %) after 3 wk exposure. Following the exposure to 42 ‰ or 15 ‰, the mortality rates in control and exposed groups were all quite low (<13 %). In late juveniles, after 3 wk exposure in SW, a higher mortality (32 %) was observed for HT-exposed shrimp compared with the control group (10 %), and the survivors at HT looked moribund. Exposure to 42 ‰ did not affect the mortality, but at 15 ‰ the mortality rates were high for MT- and HT-exposed shrimp; 30 and 100 % respectively, compared to 8 % in the control group.

In young juveniles, MT did not affect osmoregulation, and HT significantly reduced hypo-OC, by 19 % relative to the control level, but had no effect on hyper-OC (Fig. 1). In late juveniles, both hypo- and hyper-OC were reduced after 3 wk exposure to MT or HT (Figs. 2 & 3). Hypo-OC in MT- and HT-exposed late juveniles were respectively reduced by 69 % and 70 % relative to the control level, and hyper-OC of MT juveniles decreased by 35 % relative to the control level (no measurement was possible in HT-exposed late juveniles due to 100 % mortality). Similarly, Na^+ and Cl^- regulation were significantly reduced. In concentrated SW, ΔCl^- of MT- and HT-exposed late juveniles were both reduced by 64 % compared to the control level while ΔNa^+ declined by 86 and 92 % respectively (Fig. 2). In dilute SW, ΔNa^+ was reduced by 31 % and ΔCl^- by 47 % at MT (Fig. 3).

Turbidity exposure resulted in a significant increase in gill $\text{Na}^+\text{-K}^+$ ATPase activity in MT- and HT-exposed shrimp after acclimation to concentrated SW, and in MT-exposed shrimp in dilute SW (Table 2). In 42 ‰ S,

Table 1. *Penaeus japonicus*. Mortality rates in shrimp juveniles after 3 wk exposure to various turbidities in SW (36 ‰ S), and after acclimation to concentrated SW (42 ‰) or dilute SW (15 ‰)

Turbidity (NTU)	Young juveniles			Late juveniles		
	36 ‰	42 ‰	15 ‰	36 ‰	42 ‰	15 ‰
Control (2 ± 2)	7 %	7 %	13 %	10 %	7 %	8 %
MT (35 ± 15)	0 %	10 %	10 %	10 %	7 %	30 %
HT (65 ± 15)	15 %	11 %	10 %	32 %	11 %	100 %

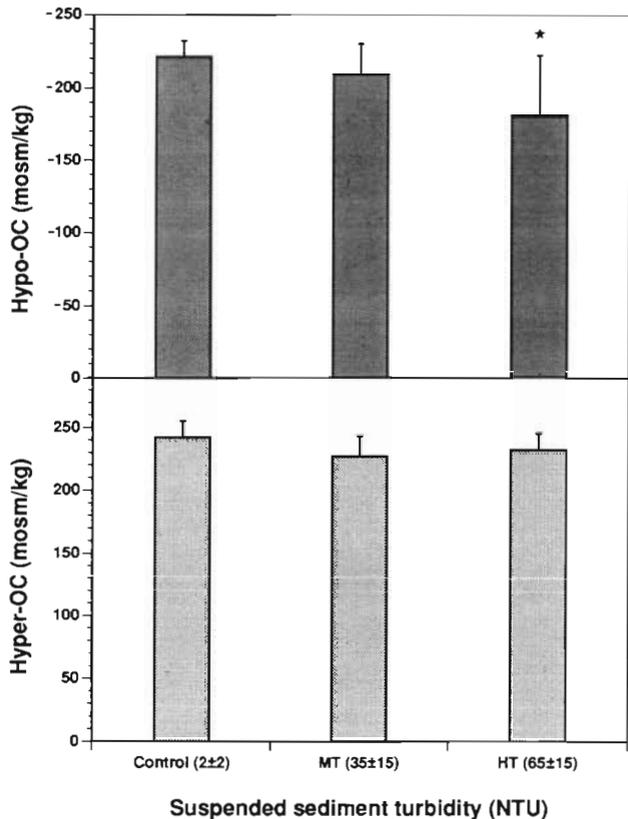


Fig. 1. *Penaeus japonicus*. Hypo-OC and hyper-OC in young juveniles in concentrated SW at 42‰ S and in dilute SW at 15‰, after 3 wk exposure to various turbidities. Each column represents the mean value of 12 to 15 determinations, with a 95% confidence interval. Comparison with the control level: *, $p < 0.05$

gill $\text{Na}^+ - \text{K}^+$ ATPase activity increased significantly with turbidity, from MT to HT. In 15‰ S, the enzyme activity at MT was also significantly higher than that of the control.

DISCUSSION

Turbidity affected survival and osmoregulation in *Penaeus japonicus* juveniles. In young and late juveniles, mortality rates increased and tolerance to salinity variation decreased after 3 wk exposure to a turbidity of 65 ± 15 NTU. Late juveniles were more susceptible to turbidity than young juveniles. In the former, OC was severely reduced at 35 ± 15 NTU or higher, which apparently resulted from impairment of Na^+ and Cl^- regulation. Gill $\text{Na}^+ - \text{K}^+$ ATPase activity increased with turbidity. Several causes could explain these effects, and most of them seem related to the action of sediments on gill functions.

Redding et al. (1987) found that in yearling coho salmon *Oncorhynchus kisutch* and steelhead *Salmo*

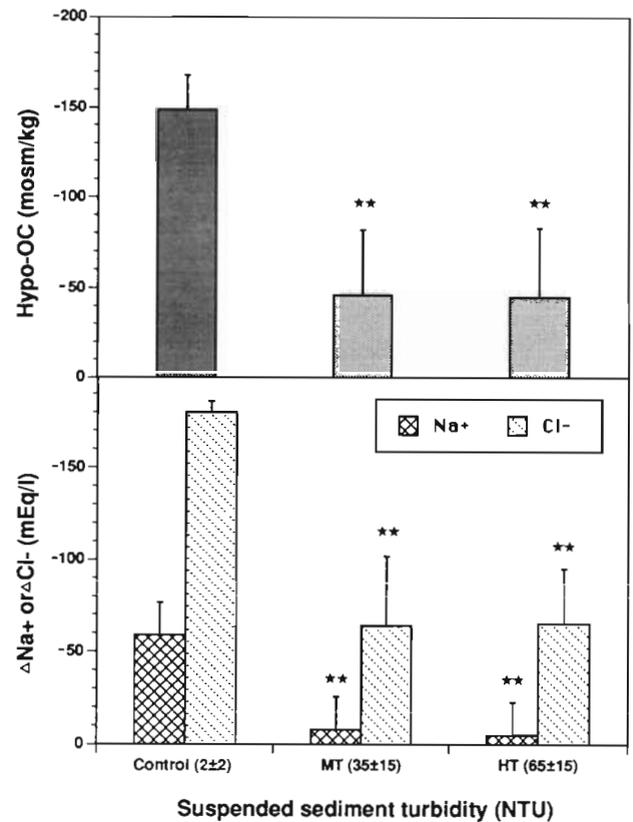


Fig. 2. *Penaeus japonicus*. Hypo-OC, Na^+ and Cl^- regulation (ΔNa^+ and ΔCl^-) in late juveniles in concentrated SW at 42‰ S, after 3 wk exposure to various turbidities. Each column represents the mean value of 7 to 10 determinations, with a 95% confidence interval. Comparison with the control level: **, $p < 0.01$

gairdneri, plasma-cortisol (an index of stress in fish) increases after exposure to 3 kinds of suspended solids: topsoil, kaolin clay and volcanic ash. But they did not observe any change in the osmoregulatory performance after transfer from fresh water to SW at 26‰ S. Servizi & Martens (1987), however, reported that suspended river sediments cause a slight impairment in the hypo-osmoregulatory capacity of sockeye smolts *Oncorhynchus nerka* and result in an increase of plasma glucose (another index of stress in fish) in adult sockeye. Thickened gill epithelia have been observed in trout exposed for several weeks to diatomaceous earth at concentrations ranging from 270 to 810 mg l^{-1} (Herbert & Merckens 1961). Fine sediments caused gill trauma of underyearling sockeye salmon *Oncorhynchus nerka* at 3148 mg l^{-1} , which is equivalent to 0.2 times the 96-h LC_{50} value (Servizi & Martens 1987). Sherk et al. (1975) observed swollen lamellae and increased numbers of goblet cells in gills of white perch *Morone americana* exposed to earth at 0.65 g l^{-1} . However, Sigler et al. (1984) did not observe any damage in gill tissue in 30 to

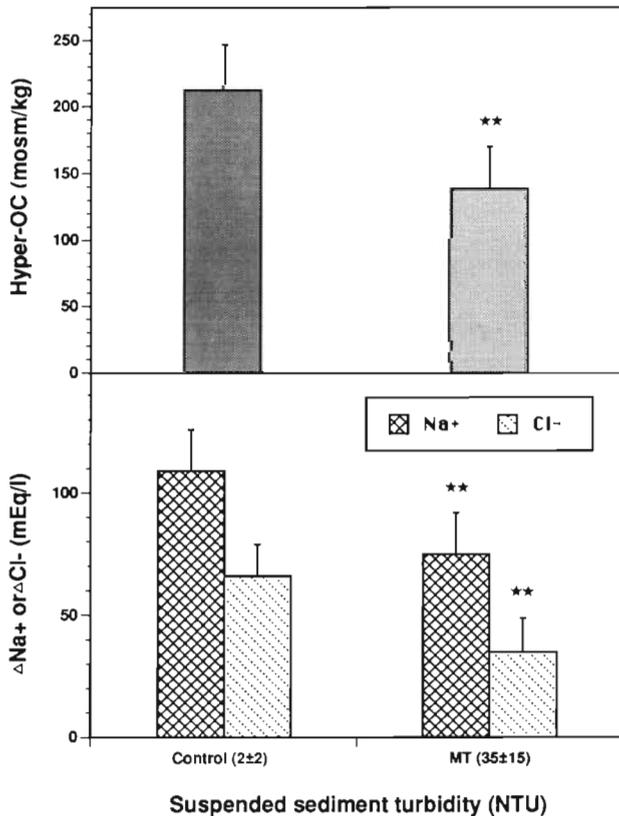


Fig. 3. *Penaeus japonicus*. Hyper-OC, Na^+ and Cl^- regulation (ΔNa^+ and ΔCl^-) in late juveniles in dilute SW at 15‰ S, after 3 wk exposure to MT (Mortality at HT was 100%). Each column represents the mean value of 5 to 10 determinations, with a 95 % confidence interval. Comparison with the control level: **, $p < 0.01$

65 mm long steelhead and coho salmon after 3 to 5 d exposure to turbidities ranging from 25 to 50 NTU. Redding et al. (1987) reported that gill tissue in yearling coho salmon and steelhead exposed to between 1.7 and 2.7 g l⁻¹ of suspended topsoil for 7 to 8 d was similar to that in the control fish.

In the present study, no visual damage was observed in the gill tissues of exposed shrimp. We found that gill lamellae were densely covered with suspended sediments and a thick layer of mucus, and that the gill chamber in dead shrimp was filled with suspended sediments. Exposed shrimp needed to continuously clean their gill chambers from excessive foreign material, which represented an energy cost and required a high metabolic rate. It has been observed that exposed coho salmon experienced gill flaring (Berg & Northcote 1985) and that exposed Arctic grayling *Thymallus arcticus* showed an increase in cough reflex (McLeay et al. 1987), which both seemed to enhance cleaning efficiency. We may thus postulate that the death of an exposed animal may be due to the incapacity to clean the accumulated suspended sediments, which could

Table 2. *Penaeus japonicus*. Gill $\text{Na}^+\text{-K}^+$ ATPase activity of shrimp late juveniles after 3 wk exposure to various turbidities and acclimation to concentrated SW or dilute SW. Values are means with 95 % confidence intervals. The number of animals used for tests is in parentheses. Comparisons (Student *t*-test) with the control level: * $p < 0.05$; ** $p < 0.01$

Turbidity (NTU)	Gill $\text{Na}^+\text{-K}^+$ ATPase activity ($\mu\text{mol P}_i \text{ mg protein h}^{-1}$)	
	42 ‰	15 ‰
Control (2 ± 2)	7.56 ± 1.54 (6)	9.79 ± 0.25 (6)
MT (35 ± 15)	9.42 ± 0.56 (6)*	13.07 ± 2.05 (4)*
HT (65 ± 15)	10.20 ± 1.58 (4)**	100 % mortality

clog gills and result in insufficient exchange of gas and ions. Some studies have also demonstrated that fish were significantly less resistant to microbial infection after exposure to suspended sediments (Herbert & Merckens 1961, Redding et al. 1987). Other causes could thus originate from secondarily induced effects of abrasions, such as attack of disease pathogens, etc.

Although the concentration of dissolved oxygen in the present exposure media was steadily maintained above 5 mg l⁻¹, it is not certain whether the actual oxygen transfer at the gill surface could sufficiently meet the presumably higher demand of exposed shrimp. Accumulated suspended sediments may clog the gill chamber and cause gill suffocation. Several studies demonstrated that exposure to suspended solids resulted in increased hematocrits in teleosts (Everhart & Duchrow 1970, Sherk et al. 1975, Redding et al. 1987, Servizi & Martens 1987, 1991). Elevated hematocrits are a compensating reaction for impaired respiration, e.g. due to hypoxia, and can increase the capacity of oxygen transfer (Redding et al. 1987). Exposed penaeid shrimps are more likely to encounter oxygen insufficiency due to their benthic inhabitat and lower efficiency of the oxygen transporter, hemocyanin, compared with that of hemoglobin in vertebrates (Truchot 1978). We may thus postulate that the mortality and adverse effects on osmotic and ionic regulation due to turbidity are at least partially attributable to reduced oxygen uptake. Charmantier, Soyez & Aquacop (unpubl.) demonstrated that in *Penaeus vannamei* juveniles, both hypo-OC in full-strength SW and hyper-OC in SW at 9.4 ‰ decreased significantly after 2 or 3 d exposure to a hypoxic condition (dissolved oxygen < 3 mg l⁻¹). Reduced haemolymph chloride was also reported in *Palaemon adspersus* and in *Crangon crangon* when the external oxygen tension was lower than the critical oxygen tension, below which the respiration rate decreases (Hagerman & Uglow 1981, 1982). The latter authors suggested that the impaired uptake can be attributed to a re-allocation of energy from ion transport to other processes when oxygen is in short supply.

Alternatively, suspended sediments may reduce the area of membrane responsible for osmoregulation, alter gill permeability to ions and water, and modify (or damage) cell structure in gill tissues, which ultimately disrupts osmotic and ionic regulation. The increase in $\text{Na}^+\text{-K}^+$ ATPase activity can enhance active ion transport, which probably represents a compensating mechanism for impaired ionic regulation (comparable to the compensating action of elevated hematocrits in fish under hypoxic conditions). On the other hand, it is important to note that gill $\text{Na}^+\text{-K}^+$ ATPase activities were measured *in vitro*, under optimal physico-chemical conditions. The impairment in osmoregulation and Na^+ and Cl^- regulation in haemolymph due to turbidity exposure may result in a modification in the physico-chemical conditions around basolateral membranes, where the enzyme $\text{Na}^+\text{-K}^+$ ATPase is localized. It is thus uncertain whether the variation in enzyme activity measured *in vitro* can represent its real physiological activity under the changed conditions. In other words, the increase in $\text{Na}^+\text{-K}^+$ ATPase activity measured may not necessarily indicate the real rate of Na^+ transport.

In addition, moult frequency is high in penaeid shrimps (Dall et al. 1990). After each moulting, suspended particles on the gills are cast off. It is not certain whether any damage or modification to gill tissues (or other body surface) due to turbidity exposure would be repaired or remain present. It is also possible that higher resistance to turbidity in young juveniles compared with late juveniles could be partially attributed to their faster moulting rate. A further study concerning the effect of turbidity on the ultrastructure of gills in exposed shrimps is presently in progress.

The present results also demonstrated that exposed juveniles could survive in concentrated SW even though their Na^+ regulation or hypo-osmoregulation was almost completely inactivated, i.e. shrimp became isoionic or isosmotic to the external medium. In contrast, in dilute SW they could not survive when ΔNa^+ or hyper-OC was reduced by more than 40%. Similar results were obtained in a previous study concerning the effect of ambient ammonia on the osmoregulation of *Penaeus japonicus* late juveniles (Lin et al. 1991). The different tolerance in OC and Na^+ regulation between SW (or concentrated SW) and dilute SW can be explained by the different osmoregulatory mechanisms in these 2 osmotic conditions. After transfer to low salinities, the osmotic pressure of haemolymph would drop, and shrimps require a quick adjustment of intracellular osmotic pressure in order to maintain normal cell volume. Otherwise, the large influx of extracellular water would considerably increase the cell volume and even prevent the normal circulation of haemolymph (Lockwood 1968). But at higher salinities

the control of cell volume becomes a less lethal factor and shrimps can thus survive even in an isosmotic (or isoionic) state.

In a field study at Aqualive (Noirmoutier), we monitored the turbidity of rearing ponds for *Penaeus japonicus* juveniles, and found that pond aerators strongly enhanced turbidity (Lin & Hatt unpubl.). In several ponds, the turbidity at the pond bottom was frequently maintained at a level close to the MT examined in the present experiment. The results of this study indicated that a sufficiently long exposure to this turbidity was at least deleterious to the physiology of juveniles at later stages. It is thus important to control pond turbidity and optimize the use of aerators; the turbidity of suspended sediments in ponds should be considered a criterion in the selection of aquacultural sites for penaeid shrimps.

Our results also indicate the need to further study the exact biological and ecological role of turbidity in natural aquatic environments. Sigler et al. (1984) found that young salmonids tend to emigrate from turbid media. Doeg & Milledge (1991) reported that the addition of suspended sediments may cause macro-invertebrate drift. It would be important to investigate whether some species are stressed at certain stages (especially in benthic and coastal or estuarine habitats), and whether their distribution or emigration is modified by the occurrence of high levels of suspended particles.

Lin et al. (1991) and Young-Lai et al. (1991) previously demonstrated that sublethal ambient ammonia caused a partial or complete impairment of osmotic and ionic regulation in *Penaeus japonicus* and *Homarus americanus*. Similarly, the present results showed that sublethal turbidity, for example 35 ± 15 NTU, resulted in a decrease in OC. This study confirms again the possibility of using OC as an indicator of physiological condition in crustaceans, particularly penaeids, as suggested by Charmantier et al. (1989). OC can provide an early warning of sublethal turbidity during the culture of penaeid shrimps. It would be very profitable to study this parameter further and use it for investigating other osmoregulating species exposed to environmental stresses.

Acknowledgements. Special thanks are due to the French Government for providing a financial scholarship to H.-P.L. We thank P. Hatt and M. Charmantier-Daures for valuable suggestions.

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