

tra of Nepal's frog consist of three energy bands, the upper and lower bands are weak in contrast to the prominent energy bands of the Indian population and the upper maximum of frequency is less than 6000 Hz. These differences may be considered as an indication of geographical variations and the possibility of the existence of a species complex.

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## Role of nematodes as bioindicators in marine and freshwater habitats

The utility of bioindicators has been established in recent times<sup>1,2</sup>. The utilization of nematodes as a tool in water quality assessment in the 1970s (refs 3 and 4) was popular and their faunal composition emerged as a useful monitor of environmental conditions and ecosystem function. The parasitic copepods, digeneans, cestodes, acanthocephala and larval nematodes have dominated in the role of parasite indicators<sup>5</sup>. But the host-parasite relationships involving adult nematodes have rarely been reported in the investigations identifying parasites as indicators<sup>6</sup>.

The subject of this investigation has been catfishes of two zoo-geographically different regions within the same country. Adult roundworms of genus *Rostellascaris*<sup>7</sup> were recovered in the two-year study (Figure 1) during 1996–98 from *Mystus tengra* of river Ganges, Allahabad. Another catfish, *Arius falcatus*, examined in the Arabian Sea at Goa during 2000–2001 revealed another species of *Rostellascaris* namely *R. oceanica*<sup>8</sup>. Studies making use of biological tags for stock delineation in intraspecific groups within a catfish host population at different geographic locations, are not very frequent. However, their role in sub-

stantiating differential spawning, nursery or feeding grounds, and behavioural forms of such groups or stocks within the same area, has been amply demonstrated<sup>6</sup>. The objective of this investigation was to analyse restrictive population distribution behaviour of the nematode parasites and

to determine useful discriminants for commercial exploitation in fish and fishery.

The nemic populations survived in marine fish stocks where hydrobiological characteristics were: salinity, 37–40 ppt; hardness, 5900–6300 mg/l; dissolved oxy-



Figure 1. Photomicrograph of the anterior end of the adult female worm *Rostellascaris oceanica* showing cephalic armature (× 620).

gen (DO), 8.3 mg/l; phosphates, 7.35 mg/l; sodium, 705 mg/l; nitrates, 45–50 mg/l; nitrites, < 5.0 mg/l; alkalinity, 170–400 mg/l; and acidity, 9.6–10.0 mg/l at the beach of Water Sports Stadium, Goa as well as at Dona Paula (salinity, 35 ppt; hardness, 6550–14750 mg/l; DO, 6.8–7.3 mg/l; phosphates, 32.75 mg/l; nitrates, > 50.0 mg/l; nitrites, < 5.0 mg/l; alkalinity, 380 mg/l and acidity, 3.5–8.0 mg/l). On the contrary, in the nematode species infested *M. tengra* in river Ganges Salinity, 6.54 ppt; hardness, 115–130 mg/l; DO, 7.4–8.0 mg/l; phosphates<sup>9</sup>, 0.25–0.65 mg/l; nitrates, < 50.0 mg/l; nitrites, < 1.0 mg/l; alkalinity, 68.0–76.0 mg/l and acidity, 1.0–2.0 mg/l were recorded.

The typical characteristics of parasites as bioindicators of pollution have been identified<sup>1,2</sup> and reviewed<sup>6</sup>. These include (i) differences in prevalence of infection and mean intensity; (ii) single-host life cycle; (iii) longer lifespan; (iv) high degree of site specificity; (v) suitable environmental conditions that should fall within the physiological range of tolerance of the parasites, and (vi) no marked pathological effect of parasite on host.

In a recent study<sup>10</sup> the advantage of using nematodes as indicators has been outlined because (i) these are among the simplest metazoa which occur in any environment providing a source of organic carbon, under all climatic conditions and in habitats that vary from pristine to extremely polluted; (ii) they do not rapidly migrate from stressful conditions and many species survive dehydration, freezing or oxygen stress; (iii) nematodes are transparent, their diagnostic internal features can be seen without dissection, and can therefore, be identified without biochemical procedures; (iv) there is a clear relationship between structure and function, and nematodes respond rapidly to disturbance and enrichment: increasing microbial activity leads to changes in the proportion of bacterial feeders in a community.

The characteristic of well-marked seasonal infrapopulation variations by *Rostellascaris* provided evidence of sensitivity to pollutant variants in the marine environments. This was particularly noticeable because, firstly, the worms of *Rostellascaris* sp. were encountered only in catfishes inhabiting the coastal waters at Dona Paula, whereas these worms did not occur in the catfish population at the beach near the Water Sports Stadium and secondly, significant variations in monthly

recruitment rate were noticed in the nemic population dynamics. This is perhaps significant in the context of inter-habitat variation in pollution levels, that the sea water at Dona Paula had higher oil spill level because of high shipping activity near the shore as well as water sports using mechanized boats, etc. being more popular at this coastal area than the beach near the Water Sports Stadium. In addition as the data would suggest, hardness levels were immensely high, along with significantly higher levels of nitrate and declining levels of DO at the former than in the latter. Thus the sensitivity of *Rostellascaris* in the current investigation confirmed this nematode amongst 'persister'<sup>10</sup> species that were more sensitive to chronic pollution than 'colonizers'. It was, therefore, inferred that the effect of pollutants is not only on reproductive potential, if the acute toxicity is highly correlated with variations in 'persister' species prevalence<sup>11</sup>.

This investigation has led a three-pronged attack: (i) opened up possibility of marine and freshwater catfish stock delineation; (ii) established adult nematodes as indicators, and (iii) explored possibility of use of parasitic indicators of hydrological conditions in marine as well as freshwater environment. In addition, the features of stout-bodied *Rostellascaris*<sup>7,8</sup> like a well-formed armature, established their edge in terms of better adaptability over other biota, besides having possessed the quality of easy detection, which is an essential requisite for being an indicator.

The adaptive response of *R. oceanica* to high salinity of marine environment in the Arabian Sea was indicative of its affinity to greater salinity compared to *R. spinicaudatum* which showed restrictive host susceptibility in freshwater ecosystems. The parasites have also been known to be the indicators of changing behaviour<sup>12</sup> of aquatic host organisms, particularly fish, that are more often exposed to predators. The roundworm, *R. spinicaudatum*<sup>7</sup>, has shown distribution all the year round in *M. tengra* at Allahabad. Similarly, *R. oceanica* was prevalent throughout the year in Arabian Sea at Goa. A longer lifespan of these nematodes has been worked out<sup>7</sup>. The correlation of their pattern of distribution in freshwater and marine ecosystems is evident<sup>6</sup>. Incidentally, the roundworms that have been the subject of the current investigation, exhibited striking affinity

to the cephalic armature<sup>7</sup> (Figure 1) akin to the human hookworm, *Ancylostoma*<sup>7</sup>, comprising cephalic interlabia. Such parasites possessing direct life cycle without the involvement of a larval stage, were better suited to a locally restricted marine/freshwater habitat, unless frequent migration of host fishes is feasible. Such an inter-habitat transfer of host fishes could possibly be the only mode of transmission of these adult roundworms. But, this kind of transfer of hosts is ruled out in the present area of study; further extension of habitat range or host range of these roundworms was not feasible.

Since the hosts, catfishes, were the only group of marine fishes out of a total of about twenty fish species examined in the Arabian Sea during parasitological investigations on the coast at Dona Paula, Goa, parasitized by *Rostellascaris*, narrow host specificity was evident in the current investigation. These characteristics, therefore, conformed to some of the strongest attributes of parasite tags. The communities of intestinal roundworms in the marine fish populations studied in the Arabian Sea exhibited features that place them among the most depauperate<sup>13,14</sup> helminth communities. These consist of a restricted number of species, either characteristic for hookworm-like species parasitizing non-fish vertebrate hosts or with low colonization abilities. A well-maintained higher level of infrapopulation richness at different geographic locations exhibited affinity to habitat characteristics, and the increased humidity enhanced intra-habitat survival and transmission ability of the helminths with direct life cycles<sup>13</sup>. In recent studies<sup>14</sup> too, strikingly similar nemic communities were sampled at the most distant localities. The authors, therefore, agree with the opinion expressed in earlier such studies<sup>13</sup> that nemic communities in geographically isolated catfishes are affected predominantly by local environmental conditions. Thus this investigation highlights that besides having been established as bioindicators, *Rostellascaris* spp. emerged as isolationist and non-interactive<sup>15</sup> species.

Nematodes are potentially useful as indicators and for setting management priorities in unique and valuable habitats. The relative rareness of indicator species could provide useful information more rapidly<sup>10</sup>. Therefore, a targeted environmental policy should be pursued to conserve and manage areas efficiently, that

provide habitat for rare animal species. The significance of such investigations to determine diversity indices in host-parasite infrapopulation interdependence and commercial output assessment would, therefore, provide long-term benefits to the fish industry in the country. The present analysis has the potential to explain the hazardous role of human activity in dispersal of parasitic species. The factual occurrence of adult worms of *Rostellascaris* spp. in water bodies at different geographic locations provided further evidence of the completion of its life cycle within the aquatic body itself. Such parasitic organisms confirmed to the description of 'autogenic'<sup>6</sup> parasites which completed their life cycles exclusively in aquatic hosts and were confined to the aquatic ecosystem, constraining dispersal. As a result 'allogenic' species capable of using vagile hosts like birds and mammals were considered to be most widely dispersed, showing broader geographic distributions than autogenic parasites<sup>16</sup>.

The present investigation is in striking contrast in *Rostellascaris* being clearly one of the most broadly distributed parasite genera in Indian fishes. This indicates possibility of inter-habitat transmission of this nematode genus to distant geographic locations by human activity, and not by any natural process, because although the Mandavi riverine system existed besides marine ecosystems at

Goa, no inter-habitat transfer of *Rostellascaris* was observed either due to salinity gradient, host's behavioral response or due to a broader host specificity. Earlier too such a word of caution has been stressed<sup>17</sup> with regard to the power of human intervention to alter natural ecological processes.

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## Vertebrate fauna from Panandhro lignite field (Lower Eocene), District Kachchh, western India

In contrast to the Middle Eocene vertebrates, our knowledge of Lower Eocene vertebrate fossils from India is extremely poor. This hampers biogeographic evaluation in a geodynamic context, particularly in regard to the mammalian evidence. The few known occurrences of pre-Middle Eocene vertebrates include those from the Subathu Formation of Himalaya<sup>13</sup>, from sediments associated with the Palana lignite in Bikaner<sup>4</sup> and, more recently, an otolith fauna from a lignite field near Surat<sup>5</sup>. During our recent fieldwork in Kachchh, we succeeded in locating a rich occurrence of fossil verte-

brates in the well-known open cast lignite mines at Panandhro. The ossiferous outcrops are located in an operational mine (HD Mine) in the Panandhro lignite field and consist of grey silty shales occurring near the top of the lignitic sequence (Figure 1). These backswamp deposits form part of the Naredi Formation, dated as Early Eocene, mainly on the basis of benthic foraminifers<sup>6</sup>. The sequence is capped by red lateritic clays.

The recovered fauna comprises fishes, turtles, snakes, crocodiles and mammals, and a checklist with tentative identifications is given in Table 1. Fishes include a

fragmentary skull of catfish, and hundreds of isolated teeth, spines and vertebrae belonging to sharks and rays. The skull, though smaller in size, appears to be conspecific with *Arius kutchensis*, already known from the Eocene of Kachchh<sup>7</sup>. The most common fish fossils are the isolated teeth and spines of *Myliobatis*. Both lateral and median teeth are present in the collection and are characterized by smooth hexagonal coronal surface and longitudinal grooves on the basal surface of the root. Associated with rays are a large number of shark teeth. *Galeocerdo*, characterized by a large