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Factors Affecting the Distribution of *Anguilla bicolor bicolor* McClelland and *Anguilla nebulosa nebulosa* McClelland (Anguilliformes; Anguillidae) in a River System of Southern Sri Lanka[1]

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Abstract

Between 1990 and 1993, *Anguilla bicolor bicolor* McClelland and *Anguilla nebulosa nebulosa* McClelland were captured using fyke nets, and physicochemical parameters were noted from the Malala Lagoon and five upstream reservoirs (Kuda Badagiriya, Badagiriya, Ranmudu Wewa, Pahalaandara Wewa and Mahagala Wewa) of the Malala River System, Sri Lanka.

Catch per unit effort (CPUE) was higher for *A. bicolor* than for *A. nebulosa* in all water bodies except in Kuda Badagiriya, from which lowest mean Secchi depth (22.7±8.1 cm) and water depth (1.10±0.27 m) and a higher CPUE for *A. nebulosa* than for *A. bicolor* were recorded. From Malala Lagoon, highest mean conductivity (4,082±2,331 μS cm^{-1}), Secchi depth (93.0±32.4 cm) and CPUE for *A. bicolor*, smallest *A. bicolor* with the lowest condition factor (K), and silver *A. nebulosa* with the highest K, were recorded. Yellow eels were captured from all reservoirs but only yellow *A. bicolor* were captured from Malala Lagoon. Mahagala Wewa, the most upstream reservoir with low conductivity, recorded highest mean length and weight for yellow eels of both species, and the highest condition factor for *A. bicolor*.

Conductivity and turbidity of water could be suggested as the major factors which affect the distribution and condition of *A. bicolor* and *A. nebulosa* in river systems of Southern Sri Lanka.

Introduction

Anguilla bicolor bicolor McClelland and *Anguilla nebulosa nebulosa* McClelland (Anguilliformes; Anguillidae) are reported from inland waters of Sri Lanka (Deraniyagala 1952; Munro 1955; Wickstrom and Enderlein 1988a, 1988b, 1991; Pethiyagoda 1991). These two eel species are known as tropical eels, one of four groups categorized under Indo-Pacific eels (Tesch 1977) and are known to co-exist in the rivers and reservoirs of Southern

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and Southeastern regions of Sri Lanka (Wickstrom and Enderlein 1988a, 1988b). *A. bicolor* and *A. nebulosa* are commonly referred to as the short-finned eel and the long-finned eel, respectively. Both species are easily distinguished from one another by several characteristic features and Schmidt's Index (Schmidt 1928) which is the most convenient character that is widely used.

These eels, which include the glass eel, elver, yellow eel and silver eel, are obligatory catadromous fish, that is, they migrate back to marine waters for spawning. They have a unique life-cycle consisting of two quite separate phases; the oceanic larval phase and the continental phase. Populations of eels within inland waters depend on the rate of recruitment of the glass eel stage and also on their rate of survival and upstream migration of elvers through estuaries and lagoons (Tesch 1977). Although the biology and distribution of *A. bicolor* and *A. nebulosa* in Sri Lanka have been studied (Wickstrom and Enderlein 1988a, 1988b; Cumaranatunga et al. 1992, 1994), little is known about the factors which affect their distribution. The primary aim of the present study is therefore to identify the factors, such as physicochemical parameters, which may influence their distribution and population size.

Materials and Methods

River System Selected for Sampling

The Malala River System, which consists of several reservoirs fed directly by the Malala River or its tributaries, was selected for the present study. Five of these reservoirs were selected for sampling: from upstream, Mahagala Wewa, Ranmudu Wewa, Pahalaandara Wewa, Badagiriya Wewa and Kuda Badagiriya Wewa; and from downstream, Malala Lagoon, which connects the Malala River System to the Sea (Fig. 1).

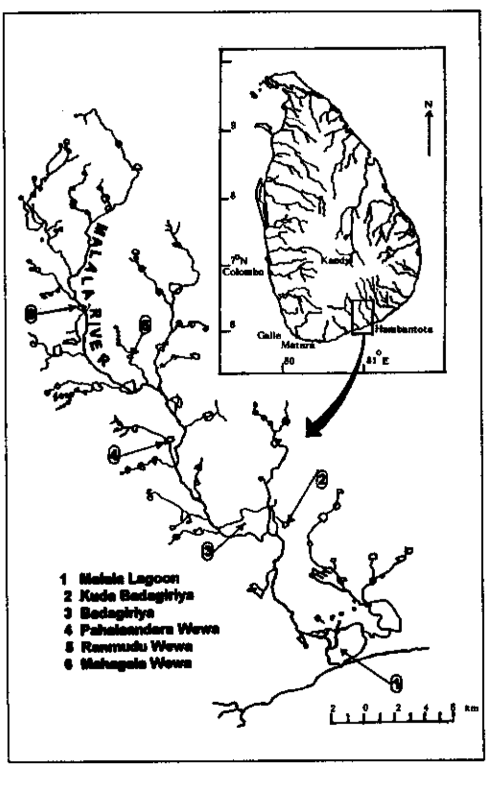

Fig. 1. Map of the Malala River System indicating all the water bodies included in the present study.

Sampling Gear

Eels were captured with fyke nets, classical eel fishing gear which are also being used for similar studies on *A. bicolor* and *A. nebulosa* from the Badagiriya Reservoir of Sri Lanka (Wickstrom and Enderlein 1988a, 1988b, 1991), and on other Anguillid eel species (Moriarty 1975; Tesch 1977, Koops 1980). These paired fyke nets were used in trains of five, joined to each other by cod-ends. Mesh size at the cod-end was 10.5 mm from knot to knot. Each train of fyke nets had both ends anchored with lead anchors (approximately 3.25 g) and marked clearly with buoys.

Sampling Duration and Strategies

Sampling was carried out from August 1990 to December 1993. At one sampling period all the water bodies were sampled within 3 d. The whole Malala River System was sampled at least three times per year. Sampling was performed during the night as daytime sampling did not yield eels during the present study and during previous studies (Wickstrom and Enderlein 1988b). Nets were set at dusk and lifted at dawn, approximately 12 h later.

Measurement of Physicochemical Parameters of Water Bodies

At the beginning and end of each train of fyke nets, depth of the water body was measured to the nearest 0.1 m. Secchi depth was measured to the nearest 1.0 cm using a Secchi disc. Water samples were obtained from the surface and bottom of each water body by a Rutner sampler, and dissolved oxygen was determined by Winkler's method (Golterman et al. 1969). Conductivity and temperature were also noted at the time of sampling. The area of each water body was measured by a planimeter using a map of the Malala River System.

Handling Eels in Fyke Net Catches

Eels were anesthetized with benzocaine. Species were identified using identification keys (Munro 1955) and Schmidt's index (Schmidt 1928; Ege 1939).

Catch per unit effort (CPUE) in terms of numbers per unit effort (NPUE) and weight per unit effect (WPUE) were determined on the basis of a unit of effort of one pair of fyke nets fished overnight.

Total length and total weight of all eels were measured. Length-weight relationships were expressed by Fulton's Condition Factor (Ricker 1975): $K = 100W \cdot L^{-3}$, where W = weight (g) and L = length (cm). Eels from all water bodies were grouped into 10-cm length groups for frequency distribution studies.

Results

Mahagala Wewa and Badagiriya Wewa are fed directly by the Malala River as these two reservoirs were created by directly damming the Malala River. Ranmudu Wewa and Pahalaandara Wewa are small reservoirs, and the tributaries connecting them to the Malala River were dry during a major part of the year, except during heavy rains. Sampling in these two reservoirs was not conducted on many occasions due to low water levels.

In all the reservoirs, numerous decaying tree trunks were present, and many of the bottoms were muddy. A major part of the Malala Lagoon consisted of submerged vegetation. The sand bar at the mouth of the lagoon facing the sea was closed most of the time, except when heavy rains forced the sand bar open, or when it was opened by human influence to prevent flooding.

Physicochemical Parameters

Mean water depth, mean Secchi depth, mean conductivity, mean dissolved oxygen, surface area, distance from the sea, and altitude of all the water bodies are given in Table 1. Malala Lagoon is the largest water body within the Malala River System, and its water had the highest mean conductivity (4,082$\pm$2,331 μS cm^{-1}) and highest mean Secchi depth (93.0$\pm$32.4 cm). Maximum conductivity recorded in Malala Lagoon was 9,810 μS cm^{-1}. Two *A. nebulosa* silver eels were captured from the Malala Lagoon when the sand bar was opened by a strong current toward the sea. The smallest reservoir, Ranmudu Wewa, had the lowest mean conductivity (200$\pm$65 μS cm^{-1}) and the lowest mean oxygen concentration (6.32$\pm$1.19 mg l^{-1}). Lowest mean Secchi depth (22.7$\pm$8.1 cm) and mean depth (1.10$\pm$0.27 m) were observed in Kuda Badagiriya Reservoir. The minimum Secchi depth of 6.0 cm and minimum depth of 0.4 m, however, were recorded from Badagiriya Reservoir during a drought when water was extremely muddy.

Distribution of Yellow and Silver Eels

Yellow eels of both species were captured from Kuda Badagiriya, Badagiriya and Mahahagala Wewa; and only yellow *A. bicolor* were captured from all the other reservoirs and the Malala Lagoon. During the entire sampling period, only one and two *A. bicolor* eels were captured from Ranmudu Wewa and Pahalaandara Wewa, respectively. Two *A. nebulosa* silver eels were recorded throughout this study, and they were from Malala Lagoon. No *A. bicolor* silver eels were recorded, but several eels close to the silver stage were captured from Badagiriya and Mahagala Wewa.

CPUE and Species Quotient

CPUE in terms of NPUE, WPUE and species quotient for all the water bodies in the Malala River System are given in Table 2. When both species were considered together, the highest NPUE was from Malala Lagoon, of which 91% were *A. bicolor*. The highest WPUE was from Kuda Badagiriya of which 76% consisted of *A. nebulosa*. Maximum values for NPUE and WPUE for *A. bicolor* were recorded from Malala Lagoon, and for *A. nebulosa* from Kuda Badagiriya. Species quotient for *A. bicolor* was higher than *A. nebulosa* for all water bodies except Kuda Badagiriya.

Table 1. Physicochemical characteristics (mean ± SD) of Malala River System August 1990 to December 1993.

Water body	Conductivity ($\mu S\ cm^{-1}$)	Secchi depth (cm)	Temperature (°C)	Dissolved oxygen ($mg \cdot l^{-1}$)	Depth (m)	Area (km^2)	Distance from river mouth (km)	Altitude from sea level (m)
Malala Lagoon								
Mean ± SD	4,082±2,331	93.0±32.4	27.2±1.5	7.60±1.25	1.13±0.32	5.93	0	0
No. of observations	11	23	24	22	24			
Minimum	1,700	30.0	25.5	5.60	0.05			
Maximum	9,810	150.0	30.0	10.20	1.90			
Kuda Badagiriya Wewa								
Mean ± SD	410±112	22.7±8.1	28.2±2.1	7.27±1.42	1.10±0.27	0.20	9	100
No. of observations	5	9	9	9	8			
Minimum	270	11.0	25.5	5.40	0.70			
Maximum	556	35.0	31.0	9.40	1.40			
Badagiriya Wewa								
Mean ± SD	515±228	25.4±11.5	27.9±1.9	7.71±1.75	1.56±0.81	4.90	10	100
No. of observations	19	21	21	21	21			
Minimum	200	6.0	24.5	5.80	0.40			
Maximum	940	50.0	31.0	11.40	3.40			
Pahala Andara Wewa								
Mean ± SD	452±63	38.0±21.9	27.7±1.0	6.90±0.75	2.26±0.47	0.12	24	200
No. of observations	5	5	5	5	5			
Minimum	410	18.0	26.5	6.00	1.70			
Maximum	545	70.0	29.0	8.00	3.00			
Ranmudu Wewa								
Mean ± SD	200±65	25.4±8.7	26.9±1.3	6.32±1.19	1.12±0.23	0.04	40	200
No. of observations	5	5	5	5	5			
Minimum	127	18.0	25.0	4.60	0.80			
Maximum	292	40.0	28.0	7.40	1.40			
Mahagala Wewa								
Mean ± SD	387±117	30.7±14.2	26.6±1.4	7.72±0.83	1.77±0.49	0.16	45	300
No. of observations	8	13	8	13	13			
Minimum	225	18.0	25.0	6.00	1.20			
Maximum	528	65.0	29.7	9.00	2.90			

Table 2. Catch per unit of effort (CPUE) in numbers (NPUE) and in weight (WPUE) for *A. bicolor* and *A. nebulosa* captured from waterbodies of the Malala River System (unit of effort = pair of fyke nets fished overnight).

Water body	Total effort (pairs of fyke nets fished overnight)	Species	Total catch				CPUE	
			No. of eels		Weight of eels		NPUE	CPUE (g)
			No.	%	Weight	%		
Malala Lagoon	661	*A. bicolor*	225	99	54,825	91	0.368	89.73
		A. nebulosa	02	1	5,389	9	0.003	8.82
		Both species	227		60,214		0.371	98.55
Kuda Badagiriya	138	*A. bicolor*	12	34	5,710	24	0.087	41.38
		A. nebulosa	23	66	18,332	76	0.167	132.84
		Both species	35		24,042		0.254	174.22
Badagiriya Wewa	561	*A. bicolor*	58	55	24,257	36	0.103	43.24
		A. nebulosa	48	45	42,557	64	0.086	75.86
		Both species	106		66,814		0.189	119.10
Pahalaandara Wewa	120	*A. bicolor*	02	100	1,903	100	0.017	15.86
		A. nebulosa	00	0	0	0	0.000	0.000
		Both species	02		1,903		0.017	15.86
Ranmudu Wewa	63	*A. bicolor*	01	100	190	100	0.016	3.02
		A. nebulosa	00	0	0	0	0.000	0.00
		Both species	01		190		0.016	3.02
Mahagala Wewa	415	*A. bicolor*	33	77	15,729	65	0.080	37.90
		A. nebulosa	10	23	8,300	35	0.024	20.00
		Both species	43		24,029		0.104	57.90

Table 3. Mean weight, mean length, length-weight relationship and condition factor of *A. bicolor* and *A. nebulosa* in the Malala River System (each pair of values was compared by a student "t" test).

Species	*A. bicolor*				*A. nebulosa*			
Reservoir	Malala Lagoon	Kuda Badagiriya	Badagiriya	Mahagala wewa	Malala Lagoon	Kuda Badagiriya	Badagiriya	Mahalaga wewa
Length (cm)								
Mean	51.4	60.3[a]	58.3[a]	60.9[a]	104.2	69.1[d]	71.5[d]	73.7[d]
±SD	8.8	14.1	12.2	12.2	4.7	17.0	15.8	11.6
Minimum	34.5	43.8	40.3	42.9	100.9	33.8	48.3	54.3
Maximum	79.0	89.5	91.5	81.8	107.5	94.9	102.8	96.3
Number (n)	221	12	58	33	2	23	43	10
Weight (g)								
Mean	245.7	475.8[a]	418.2[a]	476.7[a]	2,696.0	797.0[d]	889.9[d]	922.6[d]
±SD	171.5	404.8	298.5	230.6	285.7	586.8	742.0	629.0
Minimum	62.0	141.0	62.0	122.0	2,494.0	53.0	167.0	257.0
Maximum	1,060.0	1,430.0	1,290.0	1,175.0	2,898.0	2,260.0	2,747.0	2,324.0
Number (n)	221	12	58	33	2	23	43	9
Condition factor								
Mean	0.16	0.18[a]	0.18[a]	0.20[abc]	0.24	0.19[d]	0.19[d]	0.19[d]
±SD	0.02	0.02	0.04	0.03	0.01	0.04	0.04	0.04
Minimum	0.11	0.14	0.09	0.15	0.23	0.14	0.11	0.14
Maximum	0.23	0.22	0.30	0.28	0.24	0.26	0.31	0.26
Number (n)	223	12	58	33	02	23	43	09

[a] Significant difference from A. bicolor of Malala Lagoon (P<0.005)
[b] Significant difference from A. bicolor of Kuda Badagiriya (P<0.05)
[c] Significant difference from A. bicolor of Badagiriya (P<0.05)
[d] Significant difference from A. nebulosa of Malala Lagoon (P<0.005)

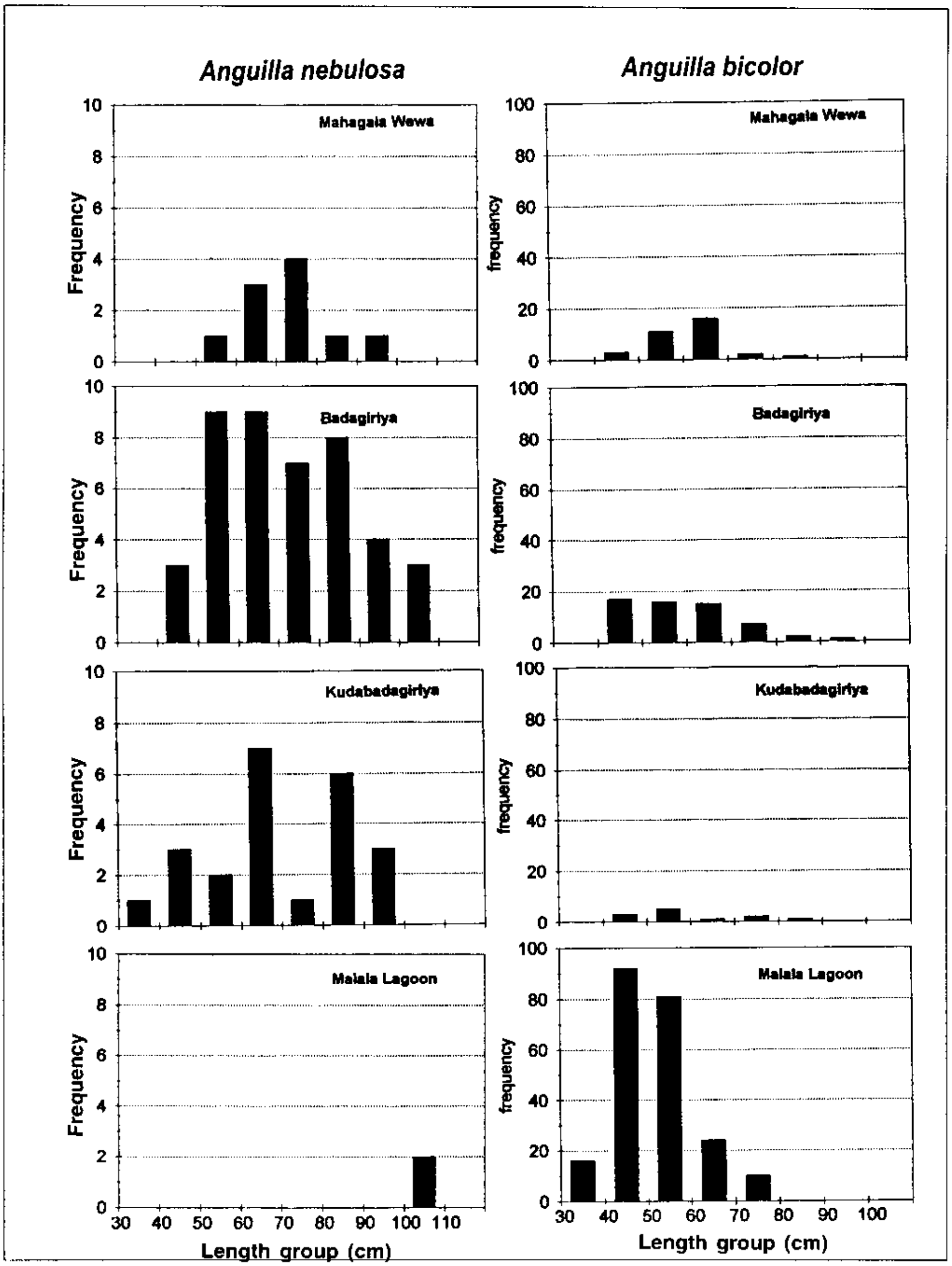

Fig. 2. Length frequency of *A. bicolor* and *A. nebulosa* in Malala Lagoon, Kuda Badagiriya, Badagiriya and Mahagala Wewa Reservoirs.

Mean Weight, Mean Length and Condition Factor

Mean length, mean weight and condition factor for *A. bicolor* and *A. nebulosa* in all water bodies are given in Table 3. Mean length, mean weight and condition factor of *A. bicolor* in Malala Lagoon, were significantly lower than in the other three major water bodies. The highest condition factor for *A. bicolor* was for eels in Mahagala Wewa, and it was significantly higher than that of eels from all the other water bodies. Most of the eels in this reservoir belong to the 60-70 cm length group which consisted of yellow eels. Mean length, weight and condition factor of two *A. nebulosa* silver eels captured from Malala Lagoon were significantly higher than in those captured from the reservoirs. These two eels belong to the <100-110 cm length group, and their mean condition factor value was 0.24±0.01.

Length Frequency Distribution

Length frequency distribution of the two eel species from the Malala Lagoon and three major reservoirs are given in Fig. 2. It indicates that the smallest *A. bicolor* and *A. nebulosa* were found in the Malala Lagoon and in Kuda Badagiriya, respectively, and the largest in Badagiriya and Malala Lagoon, respectively. The smallest length group recorded for both species was <30-40 cm, and the largest length groups recorded for *A. bicolor* and *A. nebulosa* were <90-100 cm and <100-110 cm, respectively. In Malala Lagoon where the largest number of *A. bicolor* was captured, the <40-50 cm length group was the most frequent. Similarly in Badagiriya from where the largest number of *A. nebulosa* was captured, the most frequent length groups were <50-60 cm and <60-70 cm. When the entire Malala River System was considered, the most frequent length groups for *A. bicolor* were <40-50 cm and <50-60 cm; and for *A. nebulosa* <60-70 cm (Fig. 3).

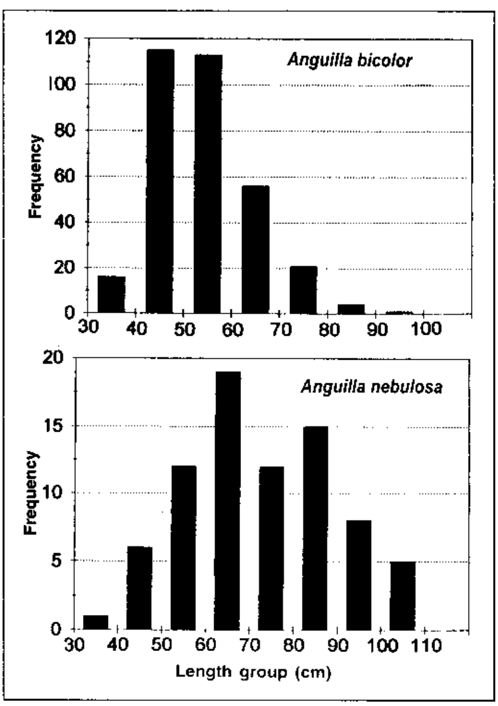

Fig. 3. Length frequency distribution of *A. bicolor* and *A. nebulosa* in the whole Malala River System.

Discussion

The highest CPUE recorded for *A. bicolor* from the Malala Lagoon and for *A. nebulosa* from Kuda Badagiriya, from where all eels captured were at the yellow stage, indicates a possible attraction of yellow eels of both species towards water with high conductivity and to freshwater bodies close to lagoons. This could also be attributed to the slow upstream migratory process of eels as described by Tesch (1977). Salinity has been indicated as one of the factors that influence activity of eels in the lower reaches of rivers. Tesch (1977) has suggested this as the reason why large populations of yellow eels are found in brackish regions of large rivers. The presence of the smallest length group (<30-35 cm) of eels of *A. nebulosa* and *A. bicolor* in Kuda Badagiriya, in Malala Lagoon indicates a possible attraction of smaller eels to water bodies close to lagoons or to those with high conductivity. The presence of *A. bicolor* in larger numbers than *A. nebulosa* in downstream water bodies, and the absence of the smallest length group of *A. nebulosa* in Malala Lagoon, suggests that *A. bicolor* is slow to migrate and that, compared to the latter, it migrates shorter distances upstream within this river system. This idea is further supported by comparing the length frequency distribution of eels in water bodies from downstream to upstream of the Malala River System. According to Moriarty (1979), population pressure is a factor promoting upstream migration and lack of pressure is known to result in slow migration; but this idea could not be applicable to *A. bicolor* and *A. nebulosa* populations found in the Malala River System.

CPUE for both species is low for all reservoirs of the Malala River System, especially when compared to the CPUE recorded in a previous study by Wickstrom and Enderlein (1991) for Badagiriya. They used a larger effort and fished a virgin population, which could explain the high CPUE. CPUE is known to be proportional to density of the population (Moriarty 1979), and therefore the low CPUE observed herein for both species of eels suggests that their population densities in the Malala River System are low.

A greater preference by *A. bicolor* than *A. nebulosa* for conditions within the Malala River System could be suggested, as the former was more abundant in the Malala River System although both species were present in all the major water bodies. Differences in habitat preference between two co-occurring species of Anguillid eels in New Zealand have been reported by Jellyman (1977). The higher species quotient observed for *A. bicolor* in all the water bodies, except in Kuda Badagiriya where it was higher for *A. nebulosa*, suggests the preference of the latter species for conditions in Kuda Badagiriya. However, a higher species quotient for *A. nebulosa* has also been observed by Wickstrom and Enderlein (1991) in the Badagiriya Reservoir of the Malala River System. This difference could also be attributed to the larger effort used during their study, and to their fishing a virgin population. In all other reservoirs included in the study conducted by Wickstrom and Enderlein (1991), species quotient for *A. bicolor* was higher, with values comparable to those observed in the present study. These observations suggest that *A. bicolor* is recruited to river systems in southern Sri Lanka in larger numbers than *A. nebulosa*. Nordeng (1971) has suggested that glass eels are recruited to freshwater as a result of their attraction to pheromones produced by the larger eels and therefore, the absence of yellow *A. nebulosa* in the Malala Lagoon could be attributed to a low recruitment rate of this eel species. *A. nebulosa* in Godawari River (India) is known to migrate 650 km upstream (Ibrahim 1961), and therefore the low quotient of *A. nebulosa* in the Malala River System could be attributed to their upstream migration to other major river systems at higher elevations and at greater distances from the Malala Lagoon when the Malala River System gets connected to them through paddy fields during rainy seasons. Further investigation, however, is necessary to confirm this phenomenon.

Fyke net sampling during the day did not result in any eel catches during the present study; similar observations have been made by Wickstrom and Enderlein (1988b) for *A. bicolor* and *A. nebulosa* in reservoirs in southern and southeastern Sri Lanka. This indicates increased night activity in these two species. Increased light intensity has also decreased the activity of Anguillid eels of other species (see review by Tesch 1977).

Considerably high catches of eels (of both species) from Badagiriya and Kuda Badagiriya, from where the maximum temperature was recorded, indicates their preference for warmer waters. The importance of temperature to the activity of young migratory eels has been demonstrated experimentally for other eel species (Tesch 1977; Jellyman and Ryan 1983).

Activity of eels is known to increase with speed of water current (see review by Tesch 1977), but Jellyman (1977) suggested that increased water flow may contribute to the onset of migration rather than being a causative factor by itself. Two *A. bicolor* silver eels (perhaps the last two of several) captured from the Malala Lagoon when there was a strong current towards the sea, suggest that a strong current may be necessary for the downstream migration of silver eels.

Depth of the water body seems to play an important role in the distribution of yellow eels of both species. The highest NPUE for *A. bicolor* was from the Malala Lagoon with a mean depth of 1.13 ± 0.32 m, and for *A. nebulosa* from Kuda Badagiriya where mean depth was 1.10 ± 0.27 m, which were the shallowest of four major water bodies within the Malala River System. *A. bicolor*, however, seems to prefer the Malala Lagoon with a high Secchi depth (low turbidity), while *A. nebulosa* seems to prefer Kuda Badagiriya with a low Secchi depth (high turbidity).

The lowest CPUE was recorded from Ranmudu Wewa and Pahalaandara Wewa, which recorded the lowest mean dissolved oxygen concentrations compared to four major water bodies in the Malala River System. This indicates that both eel species are less attracted to water with low dissolved oxygen concentration.

The highest and lowest recorded condition factors for *A. bicolor*, from Mahagala Wewa and Malala Lagoon, respectively, indicate a relationship between the condition of these eels to the physicochemical factors of the two water bodies. Mahagala Wewa, the most upstream reservoir, recorded the highest mean depth and dissolved oxygen concentration, and lowest mean temperature and conductivity. Malala Lagoon, the most downstream water body, recorded the highest conductivity and Secchi depth (low turbidity). This may indicate negative effects of high conductivity, temperature and turbidity and positive effects of high dissolved oxygen concentrations and water depth on the condition factor of *A. bicolor*. The highest condition factor recorded for two *A. nebulosa* silver eels, captured from the Malala Lagoon, and significantly low condition factors recorded for *A. nebulosa*, which were captured at the yellow stage from other water bodies, indicate that the best condition factor is found in silver eels which migrate towards water with high conductivity or towards lagoons that open to the sea.

A. bicolor and *A. nebulosa* co-occur in the river systems of Southern Sri Lanka, but *A. bicolor* is more abundant and shows a slow upstream migratory process compared to the latter. Conductivity and turbidity are two major physicochemical parameters which affect the distribution and condition factor of these two eel species within the rivers and reservoirs of Southern Sri Lanka. The low recruitment rate of *A. nebulosa* and the slow upstream migratory process of *A. bicolor* also may influence their distribution within the river systems of Southern Sri Lanka.

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