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Effect of water depth and salinity on the population of Greater Flamingo (*Phoenicopterus ruber*) in Point Calimere Wildlife and Bird Sanctuary, Tamilnadu, Southern India

T. Sumathi, R. Nagarajan* and K. Thiyagesan

PG and Research Department of Zoology and Wildlife Biology, A.V.C. College (Autonomous), Mannampandal – 609 305, Mayiladuthurai, Tamil Nadu, India

Abstract

The changes in the population of Greater Flamingo (*Phoenicopterus ruber*) and influence of water depth and salinity on its population were investigated in the Point Calimere Wildlife and Bird Sanctuary, Tamilnadu, Southern India between 2004 and 2006. The mean density of Greater Flamingo ranged from 0.99 to 1656.73 km^2 for the entire study period. Interestingly, in all the years of study the Greater Flamingo could not be recorded in June and September in the present study area. The density was highest in areas with 15-20 cm water depth irrespective of salinity levels. The density of flamingo was lesser in the metahaline areas (areas with salinity of 40-80 ppt) than that of the other areas. The flamingo density among the areas of depth categories ($F_{3,191}$= 6.34; P < 0.001) and of different salinity levels ($F_{3,191}$=9.75; P< 0.001) varied significantly. There was a significant association between the water depth categories and salinity levels (χ^2_9 =137.6; P < 0.001). In lower saline areas, the flamingos used deeper waters and on the other hand in the higher saline areas they preferred shallow waters. The salinity had quadratic effect whereas the water depth had cubic influence on the density of flamingos. The Standardized Partial Regression Coefficient (β values) indicated that the salinity had the prime influence followed by water depth on the population of flamingo. When the water depth was taken into account, the prediction showed that the increase in salinity of more than 10 ppt significantly decreased the population of flamingos until the salinity of 40 ppt. On the other hand, the population of flamingo increased significantly from the water depth of 9 cm and attained the peak at 21 cm. The result suggests that the water salinity would have influenced the prey abundance and depth would have influenced the accessibility of prey.

Keywords : Greater Flamingo, foraging, Point Calimere, population, Ramsar site, salinity, water depth

INTRODUCTION

Flamingos (Phoenicopteridae) are highly specialized filter feeders with their beak well adapted to feed on very small particles, compared to other birds of similar size (Mascitti and Kravetz, 2002). Greater Flamingo (*Phoenicopterus ruber*) is larger and feeds mainly on invertebrates such as brine flies (*Ephydra*), shrimps (*Artemia*), molluscs (*Cerithium*), chironomids, polychaetes and amphipods which they obtain from mud by ooze feeding (Ali, 1981). From time immemorial, flamingos are the regular visitors of Point Calimere Wildlife and Bird Sanctuary, South India and they use this sanctuary as their main wintering ground in India (Baruah, 2005) and foraging mainly on the plankton rich areas in Point Calimere Wildlife and Bird Sanctuary (Sumathi *et al.,* 2007a). But of late, population of flamingos in this sanctuary which usually fluctuated narrowly around 20000 individuals upto two decades ago declined drastically to 3351 in 1986 and mere 350 in 1995 (e.g. Nagarajan and Thiyagesan, 2006), indicating deterioration in the habitat quality of this area.

Indeed the evolution of life history strategies of birds and their migratory patterns over evolutionary time were shaped by habitat quality especially the abiotic factors which serve as proximate cues in initiating migratory behavior in any given year (Burger, 1984). Though the importance of abiotic variables has long been recognized in the habitat utilization of birds by several authors (e.g. Patterson, 1976; Murphy *et al*., 1984), only recently have investigators concentrated on finding out how particular abiotic factors affect shorebirds (e.g. Nagarajan and Thiyagesan, 1996; Takekawa *et al.,* 2006; Nagarajan *et al.,* 2008). Considerations of water quality is important in waterbird habitat evaluation because a host of interacting physical and chemical factors can influence the level of primary productivity in aquatic systems and thus influence the trophic structure and total biomass throughout the aquatic food web (Wetzel, 1975). Indeed a relationship between water quality and waterbirds had already been indicated by several studies (e.g. Patterson, 1976; Murphy *et al.,* 1984; Nagarajan *et al.,* 2006). It has been inferred that the physiochemical characteristics of the water largely determine the waterbird community of aquatic habitats, primarily by their direct and indirect impact on the availability and abundance of the birds' prey (e.g. Nagarajan and Thiyagesan, 1996).

Salinity plays a significant role in aquatic environments, especially in variable saline habitats such as estuaries,

*Corresponding Author
email: *r.nagarajan@ex.ac.uk*

swamps, and lagoons. Organisms which live in a saline environment are sensitive to changes in its salinity (e.g. Nagarajan *et al.,* 2006). The variations in the salinity gradient in an environment could affect the distribution, growth and survival of organisms (e.g. Ramamurthy, 1965; Murray 1980; Akberali *et al.,* 1983; Westerbom *et al.,* 2002). It is also well established that the changes in the salinity could influence the population of plankton, benthic organisms and macro invertebrates in aquatic ecosystems (e.g. Ramachandran *et al.,* 1965; Britton and Johnson, 1987) which are the major food sources for top level predators including birds and mammals.

Since the aquatic habitats are dynamic in nature, the level of the substratum (water) fluctuates rapidly within a day due to tide and the annual variations caused by precipitation and evaporation. Such variation in water depth largely determines the habitat use of birds (e.g. Sayre and Rundle, 1984; Poysa, 1989; Rostogi and Pathak, 1990). Birds that feed on aquatic habitats use a variety of foraging techniques from diving (cormorants, shags and pelicans) to mud probing (plovers and sandpipers). Therefore the wide variation in water depth across the day and season could influence the population dynamics i.e. density, diversity and richness of water birds in aquatic habitats. Nagarajan and Thiyagesan (1996) emphasized that the habitat selection and changes in waterbird population are primary influenced not only by prey availability but also by their accessibility, which in turn is largely influenced by water depth.

From the foregoing discussion, it is clear that the salinity could influence the density and diversity of prey organisms, i.e. food availability, and the water depth the accessibility of the prey. Hence in this study we assess the changes in the population of Greater Flamingos in relation to water salinity and depth across the years between 2004 and 2006 in the Point Calimere Bird and Wildlife Sanctuary in order to evaluate the significance of these two factors in the recent decline of Greater Flamingos in this Sanctuary.

STUDY AREA

The Great Vedaranyam Swamp adjoining the Point Calimere Wildlife and Bird Sanctuary is located along the Palk Strit in the Nagapattinam district of Tamil Nadu, South India. It lies between 79.399° E and 79.884° E and 10.276° N and 10.826° N covering in area of about 38.500 hectares from Point Calimere in the east to Adirampattinam in the west (10°18’N; 79°51’ E and 10 °21’N; 79° 25’E) (Fig. 1). The Point Calimere Wildlife and Bird Sanctuary was declared as a Ramsar site on 19th August 2002. Bio-geographically this Ramsar site is a mix of salt swamps, mangroves, backwaters, mudflats, grasslands and tropical dry evergreen forest. Two industrial salt companies Chemplast (Chemical and Plastics Limited) and DCW (Dharangadhra Chemical Works) and a number of small and large salt units that produce edible salt and industrial salt operate in this area.

Study Site

The Great Vedaranyam Swamp stretches for about 48 km from east to west, parallel to Palk Strait separated from it by a sand-bank. There is a gradual north-south slope. In total, it has an area of about 349 km^2 (Kodiakkarai Swamp) (Fig. 1). It is a continuous sheet of fresh, brackish or saline water up to the tip of its northern boundary during the monsoon and the period of the south westerly winds. Thus Great Vedaranyam Swamp comes under the category of “bar-built” estuaries (Pritchard, 1967).

The present study area, a part of the swamp, is about 3500 acres in extent. It has two water pumping stations and reservoirs nearby. Five fresh water channels empty into this part of the swamp. The swamp contains water only during the monsoon and in the summer the water gets dried up gradually and in the perk summer a small pool of water can only be seen.

The entire swamp belt is about 30 km long and 9 km wide. It is screened from the Bay of Bengal and Palk Strait by narrow strips of sand banks with many opening. The most important openings to the sea from the swamp are “*Manavaykal*” and “*Sellakkani*” mouths. Sea water enters to the eastern half of the swamp mostly through these openings. The swamp and Palk Strait are connected by a small channel near the jetty region. The Kodiakkarai swamp represents a mixed ecosystem, influenced by both fresh water and seawater. The extensive mud flats of swamp area have many variations of water quality depending upon the season. During monsoon time the whole swamp area experience wide variation of water quality depending upon the rainfall. The swamp area is covered by fresh water in monsoon. During summer (April and June) swamp area has high saline condition and the salinity sometimes increases even up to 70 ppt (Sumathi *et al.,* 2007b). Large tracts of hard packed mudflats are exposed during summer (Anbazhagan, 1988).

MATERIALS AND METHOD

Study Period

Data were collected from January 2004 to December 2006 which included four seasons *viz*., Post-monsoon (January-March), Summer (April -July), Pre-monsoon (August and September), and Monsoon (October-December) of three successive years. In the three years, the swamp got dried during June. So data were not collected in June of all the three years of study. The Greater Flamingo was not seen during post-monsoon season of 2004, summer of 2005 and pre-monsoon of 2006.

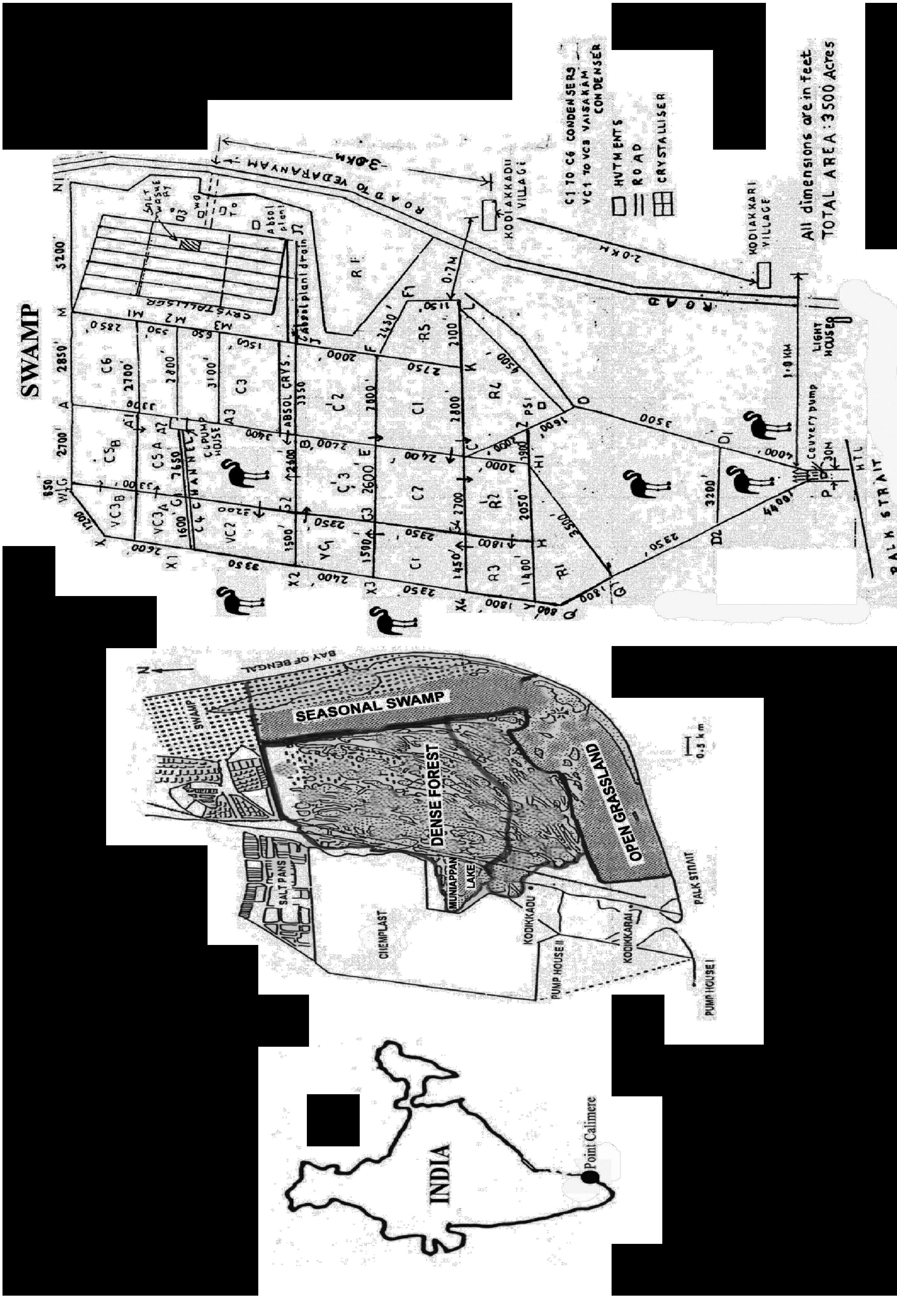


Figure 1. Map of study area and study sites

Population Studies

The flamingos were observed through a 7'x50" field binocular and a 30 x 60 telescope. The population of flamingo was measured at least twice a week across the study period using direct total counts (Nagarajan and Thiyagesan, 1996) and the density was expressed as number / hectare. Counts were not made on days with rain, strong wind or extreme temperatures to minimize the bias caused by the effect of weather.

Measurement of water depth and salinity

The water depth and salinity were measured twice a week across the study period. A measuring chain and scale were used to measure the depth of water column with an accuracy of 1 cm (Nagarajan and Thiyagesan, 1996). The salinity was measured using a refractometer with an accuracy of 1 ppt (Sant'Anna *et al.,* 2006).

The flamingo was found to forage in waters of 3 to 38 cm depths. The bill length of male and female Greater Flamingo range from *c.* 13.9-16.4 cm and 12.0 -14.3 cm, respectively (Ali and Ripley, 1983). Hence the range of water depth is classified as <5 cm, 5-10 cm, 10-15 cm, 15-20 cm and >20 cm for analysis. The salinity in this area during the study period ranged from 7 to 68 ppt. Hence the range of salinity is classified as mesohaline (5-18 ppt), polyhaline (18-30 ppt), mixoeuhaline (30-40 ppt) and metahaline (40-80 ppt) based on the classification of Por (1972) which followed the Venice System (1959).

Statistical analysis

Statistical analyses were performed by using window based statistical package Minitab. The difference in the population of flamingos among the depth categories and different saline areas was explored using Two-Way Analysis of Variance. The association between different water depths and various saline areas was assessed using contingency table model Chi-square test. Cell modifications were made to fulfill the requirements of Chi-square analysis.

The effect of water depth and salinity on the population of flamingo was investigated using multiple regression equation model. The flamingo population (density) was regressed against water depth and salinity in iterative stepwise multiple regression. We developed regression models using both step-up and step-down procedures. In all the regression models, assumptions about the nature of the data such as

i) The relationship between the response variable (also called 'dependent variable') and predictor variable (independent variable) is linear.

ii) Homogeneity of variance: the residuals in Y axis should not show a tendency to increase or decrease as X axis (Fits) increases, which is called 'heteroscedasticity' or 'shotgun effect' (Watt, 1998)

iii) The residuals have normal distribution were tested.

To investigate relationship between the response and predictor variable, the raw data was plotted by using Minitab's Lowess plot. If the figure showed a linear trend then the variable was entered in the regression model in linear form, if it was a curve then both linear and quadratic form (square the variable) were used. In the step-up procedure, the first step was entering the most influential predictor variable in the model, and then the residuals of that model were plotted against fits to explore the heteroscedasticity problem. The third assumption i.e., normal distribution of residuals was tested using the histogram of residuals. At the end, the final refined model was derived using water depth and salinity with appropriate higher order terms without violating the above assumptions (Nagarajan *et al.,* 2002a,b).

RESULTS

Water depth

The depth of water column in the foraging grounds of Greater Flamingo ranged from 3 to 38 cm across the study period. The mean depth fluctuated widely across the months in the I year (2004). In the II year, the water depth was almost consistent until September 2005 except between April and July when the swamp got dried and then increased towards the end of the year. The water depth increased gradually until April 2006 (in the III year). It was consistent between October 2006 and November 2006 and decreased to the lowest during December 2006 (Fig. 2).

Water salinity

The salinity of the foraging patches of Greater Flamingo ranged from 7 to 68 ppt across the study period. The salinity was lowest during November and December in 2004 and 2005, respectively. In the III year, it was lowest during October 2006. No clear pattern could be discerned from the salinity fluctuations across the months in all three years of study (Fig. 2).

Flamingo density

The mean density of flamingo ranged from 0.99 to 1656.73 km^2 for the entire study period. In all the three years of study, no flamingo was observed during the months of June and September and the highest density recorded were 415.62 / ha for I year (December 2004), 937.06 / ha for II year (December 2005) and 514.14 / ha for III year (November 2006).

In the I year (2004), the density was lowest during May 2004 which gradually increased to the highest during December 2004. In the II year (2005) also the same trend was observed but the lowest density was during January 2005. On the other hand in the III year (2006), the population of flamingo fluctuated widely and no clear pattern was observed (Fig. 2).

The mean density of Flamingo was lowest in <5cm depth, which slightly increased and was almost same in 5-10 and 10-15 cm water depth and was highest in 15-20 cm and >20cm deep waters (Fig. 3). The mean density of flamingo was highest in mesohaline area (5-18 ppt) and lowest in metahaline (40-80 ppt) (Fig. 4) areas.

The density of Greater Flamingo showed variations due to differences in water depth of various saline habitats (Fig. 5). Flamingos were not recorded in <10 cm depth of mesohaline and polyhaline areas and also in areas of more than 20 cm depth in mixoeuhaline and metahaline areas. The density was highest in 15-20 cm deep areas in all saline areas except metahaline where the density was highest in 5-10 cm depth (Fig. 5). The difference in flamingo density among the depth category ($F_{3,191}$=6.34; P< 0.001) and different salinity areas ($F_{3,191}$=9.75; P< 0.001) showed significant variations.

Foraging visits made by Flamingo

The foraging visits made by flamingos in different depth categories varied remarkably in relation to different saline areas. The percentage of foraging visits in mixoeuhaline and metahaline was highest when the water depth was 5-10 cm. In polyhaline areas the flamingo frequently used areas with 10-15 cm deep waters. In mesohaline the birds preferred to use 15-20 cm water depth areas followed by 10-15 cm depths (Fig. 6). A 4x4 contingency Chi-square test (>20 cm category was merged with 15-20 cm due to fewer frequencies) indicated that there was a significant association between the saline areas and water depth categories (χ^2_9 =137.6; P < 0.001). In lower saline areas the flamingos used deeper waters and on the other hand in the higher saline areas they preferred shallow waters.

Effect of water depth and salinity

The effect of water depth and salinity on the population of Greater Flamingo was investigated using multiple regression equations. The salinity had quadratic effect whereas the water depth had cubic influence on the density of flamingos. The model was highly significant and explained 23.1% of variance (Table 1). The predictions were extrapolated to investigate the quadratic and cubic effect of salinity and depth, respectively. When the water depth was taken as constant, the prediction indicated that the increase in salinity of more than 10 ppt significantly decreased the population of flamingos until 40 ppt salinity and above 41 ppt the population started to increase (Fig. 7). On the other hand the population of flamingo increased significantly from the water depth of 9 cm and attained the peak at 21 cm, when the salinity was kept constant (Fig. 8).

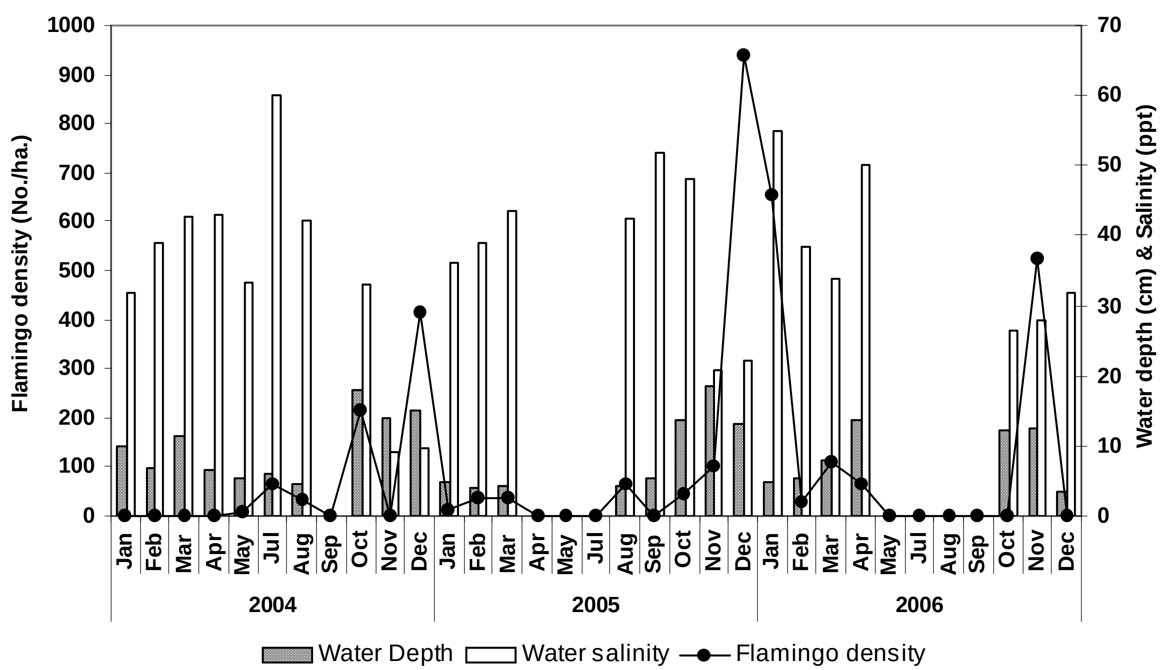


Figure 2. Comparison of the fluctuations in the population density of Greater Flamingo with water depth and salinity in different months from January 2004 to December 2006 in the swamps of Point Calimere Wildlife and Bird Sanctuary.

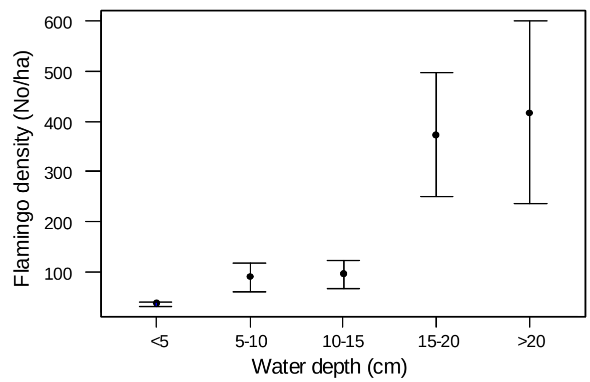


Figure 3. Density of Greater Flamingo at different water depths in the swamps of the Point Calimere Wildlife and Bird Sanctuary. Vertical lines represent mean ± 1

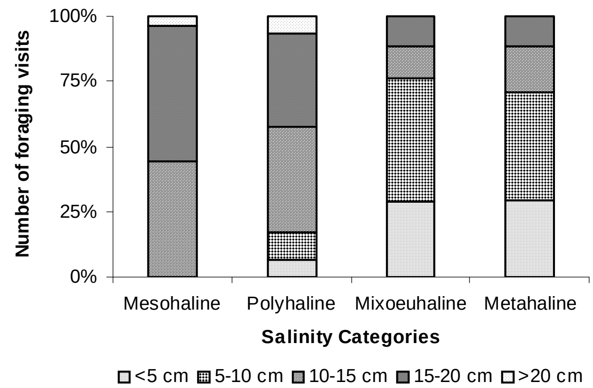


Figure 6. Percentage use of different depths of various saline areas in the swamps of the Point Calimere Wildlife and Bird Sanctuary by Greater Flamingo

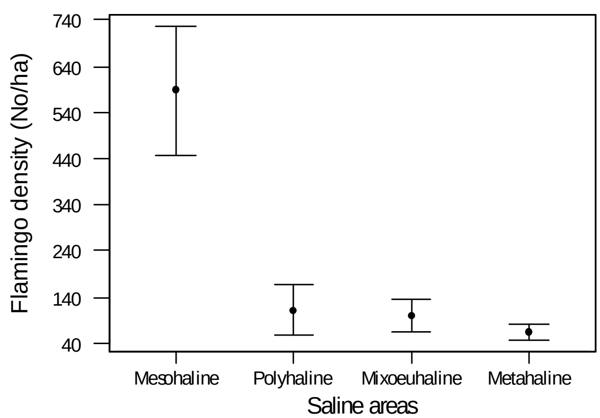
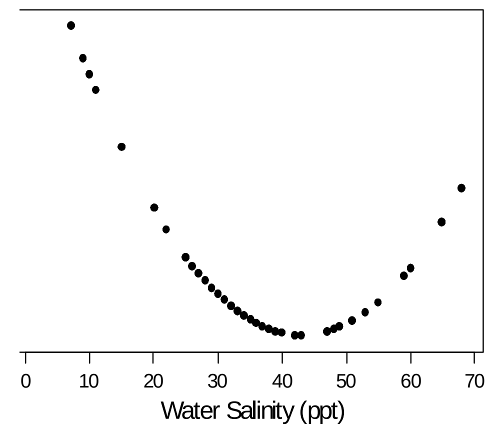


Figure 4. Density of Greater Flamingo in different saline areas of the swamps of the Point Calimere Wildlife and Bird Sanctuary. Vertical lines represent mean ± 1 *S.D.*



The predicted Greater Flamingo population ...rent values of salinity when the water depth

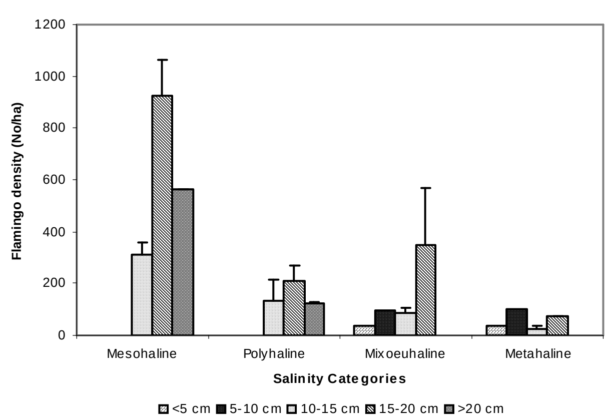


Figure 5. Density of Greater Flamingo in different depths of various saline areas of the swamps of the Point Calimere Wildlife and Bird Sanctuary. The bars show the means and the vertical lines + 1 *S.E.*

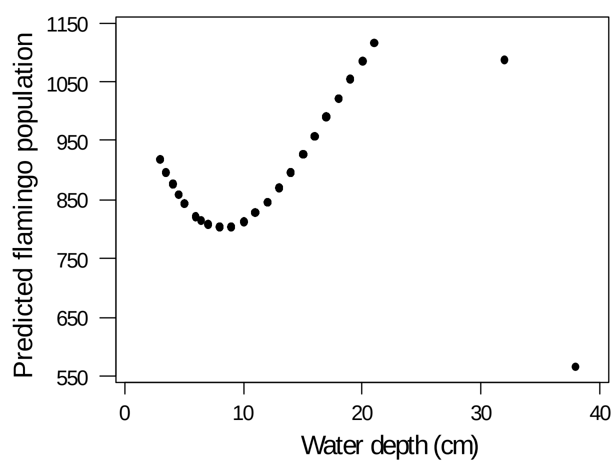


Figure 8. The predicted Greater Flamingo population for different values of water depth when the salinity was kept constant. The multiple regression equation given in table 1 was used for prediction

Table 1. Multiple regression equation model to investigate the effect of water depth and salinity on the populations of Greater Flamingo in the swamps of Point Calimere Bird and Wildlife Sanctuary between January 2004 and December 2006

Dependent Variable	Predictor variables	Coefficient	SPRC[a] or β values	t	P	Model F & P	R^2
Greater Flamingo density	Constant	1156.2 ±194.0	---	5.96	<0.001	11.54	23.1%
n =198	Salinity	-39.742±7.033	-1.722	-5.65	<0.001	<0.001	
	Salinity^2	0.4598±0.0838	1.610	5.48	<0.001		
	Depth	-85.06±31.62	1.455	-2.69	<0.01		
	Depth^2	6.756±2.281	3.365	2.96	<0.01		
	Depth^3	-0.1292±0.0422	-2.089	-3.06	<0.01		

[a]Standardized Partial Regression Coefficients

The effects of water depth on the salinity is shown in figure 9. The water depth had a cubic relationship in influencing the salinity of the habitats.

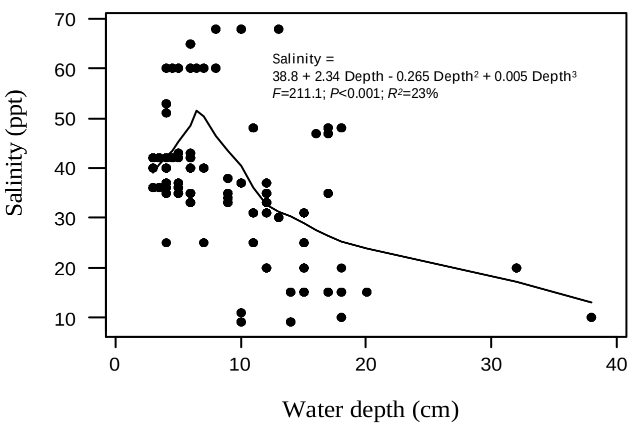


Figure 9. Scatter plot shows the relationship between salinity and water depth. The line shows the weighted mean. Multiple regression equation showing the cubic relationship and the model F, P and R^2 values are given

DISCUSSION

We observed that the density of Greater Flamingo was highest in 15-20 cm depth in all saline areas. Water depth has been reported to be an important factor affecting the distribution and density of water birds (Nagarajan and Thiyagesan, 1996). Sayre and Rundle (1984) found that the water depths to be an important factor influencing habitat use by Migrant Soras and Virginia Rails at the Mingo National Wildlife Refuge in southern Missouri, U.S.A. Role of water depths in the wetland use by water birds had also been documented by Poysa (1989) for teals and Rostogi and Pathak (1990) for cormorants and coots. Sridharan (1989) found significant correlation between the population of resident ducks, the total quantum of water and water depth in Keoladeo National Park, Bharatpur, India. Taylor *et al*. (1992) found that there was a great variation in numbers of shore birds on wet mud flats from week to week and from year to year, and at least some of this variation was caused by water level fluctuations and mudflats exposure timing. Earlier in Great Vedaranyam Swamp, the Lesser Flamingos was observed to feed in less than 5 cm water depth and they were reported to always avoid deep water in reservoirs and fed standing on old submerged bund near the shore (Manakadan, 1992). Hence water depth appears to be the main reason for the habitat utilization of Greater Flamingos in Point Calimere Wildlife and Bird Sanctuary.

In the study area, among the four saline areas, the metahaline area (40-80 ppt) had lesser density than that of other areas. Indeed salinity had been reported to influence to a large extent the succession and dominance of various aquatic organisms. Diatoms were found to be high in the North Kanara coast when the salinity was low (Ramamurthy, 1965). Britton and Johnson (1987) found that invertebrate diversity decreased dramatically in the 40-70 ppt salinity range and remained at that level until about 150 ppt in the areas of salt works in France. Furthermore higher salinities were reported to cause reduction in the prawn and fish diversity and abundance as well (Ramachandran *et al.,* 1965). Carpelan (1957) found a transition region (salinity 50-80 ppt) to be devoid of either the marine organism found in low salinity ponds or of the brine shrimp that dominated in the high salinity ponds at salt company ponds in California. Interestingly, Baldassarre and Arengo (2000) found that most food was found in the low-salinity ponds (63-73 ppt) and high salinity ponds (147-205 ppt); no food was found in intermediate salinity ponds (78-136 ppt). As such this kind of influence by salinity would have yielded the quadratic relationship observed to this present study. The bill length of the male and female Greater Flamingos ranged from *c.* 13.9–16.4 cm and 12.0-14.3 cm, respectively, and so a foraging depth between 9 and 21 cm would be the optimum depth for the flamingos for effective filter feeding. Espino-Barros and Baldassarre (1989) investigated the habitat utilization of flamingo and found that the salinity within the three man made habitats ranged from 80 ppt (low salinity salt ponds) to 206 ppt (high salinity canal); however, flamingos never were observed in the final series of ponds (crystallizers) where salinity readings exceeded 206 ppt. On the contrary to our study, Arengo and Baldassarre (1998) found that in their high salinity ponds (145-210 ppt), most food was available in the water column, whereas most food in the low salinity ponds (45-77 ppt) and in the lagoon was available in the substrate in the foraging areas of American Flamingo (*P. ruber*). However, the impact of salinity on birds is mainly indirect, as is the prey species of birds, rather than the birds themselves, that affected by increasing salinity (Burger, 1984; Manakadan, 1992).

The salinity was found to have quadratic effect whereas the water depth had cubic influence on the density of flamingos and in which the salinity had the prime influence followed by water depth (vide Table 1). The Standardized Partial Regression Coefficient or beta value of salinity (β = 1.722) was higher than that of the water depth (β = 1.610) which indicated that the salinity had the prime influence followed by water depth. Further, we observed that there was a significant association between the salinity and water depth categories in relation to habitat utilization of flamingo's. In lower saline areas, the flamingos used deeper waters and on the other hand in the higher saline areas they used shallow waters for foraging. When the relationship between salinity and water depth was analysed, the salinity was found to have a cubic relationship (vide Fig. 9). So, it is inferred that the salinity is the prime factor that determined the quality of the foraging habitats of the flamingos and the flamingos selection of foraging depths is a reflection of water depth on salinity. The changes in the salinity would have influenced the diversity and abundance of the aquatic organisms which were the major food sources for flamingos. In addition, the water depth was the variable that could have determined the accessibility of the prey. In fact the selection of different depth by flamingos would provide information about the salinity gradients.

Thus water salinity and depth seemed to have played vital roles and we conclude that decreased water availability due to insufficient monsoons and inadequate release of water in to the rivers of the study area might be a crucial factors for the alarming decline in the flamingo population in the sanctuary of late.

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