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Movement Patterns and Site Fidelity of River Dolphins (*Inia geoffrensis* and *Sotalia fluviatilis*) in the Peruvian Amazon as Determined by Photo-Identification

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Abstract

Photo-identification was used to examine range, rate of movement, and site fidelity of the river dolphins (*Inia geoffrensis* and *Sotalia fluviatilis*) in Peru's Pacaya-Samiria Reserve from 1991 to 2000 (field work conducted all years and all seasons). Dolphins were identified by scars, cuts, nicks, pigmentation patterns, and abnormal beaks. Seventy-two *Inia* and 7 *Sotalia* were identified, and 25 *Inia* and one *Sotalia* were resighted. Sighting histories ranged from 1 d to 7.6 y. Maximum range of movement for *Inia* was 220 km, with a mean range of 60.8 km. Maximum range for *Sotalia* was 130 km. The greatest rates of movement observed were 120 km/2 d for *Inia*, and 56 km/9 h for *Sotalia*. The mean rate of movement was 14.5 km/d for *Inia* and 56 km/d for *Sotalia*. Identified dolphins were not observed to move between surveyed tributaries of the Marañón River but, instead, were always observed within the same tributary system. Ninety percent of all *Inia* resighted in one river system were seen in the same lake at least once, and 33% of dolphins resighted in the lake were never seen outside of the lake. Although photo-identification yielded new information about river dolphin movements and site fidelity, its utility was limited due to behavioral, morphological, and ecological characteristics of these cetacean species.

Key Words: river dolphins, *Inia geoffrensis*, *Sotalia fluviatilis*, site fidelity, movement patterns, range, photo-identification, Peru, Amazon River

Introduction

The South American river dolphins, *Inia geoffrensis* (Boto) and *Sotalia fluviatilis* (Tucuxi), occur in the Orinoco and Amazon River Basins, where in many parts of their range they experience habitat degradation due to pollution, river traffic, deforestation, hydroelectric dams, and overfishing of their prey by humans. They are sometimes killed incidentally during human fishing activity, including gill-netting and dynamite fishing (Best & da Silva, 1989). On occasion, *Inia* are deliberately killed by fishermen, who are attempting to protect their nets or reduce the dolphins' take of fish (Leatherwood, 1996; Reeves et al., 1999); and in recent years, *Inia* in Brazil and Colombia have been reportedly killed for use as bait in a commercial fishery (Martin & da Silva, 2004b).

Although much of the area of distribution of *Inia* and *Sotalia* is unprotected, river dolphins do occur in protected areas of countries throughout their range (e.g., Santos Luzardo National Park in Venezuela, Pacaya-Samiria National Reserve in Peru, Mamirauá Reserve in Brazil, and Noel Kempff Mercado National Park in Bolivia). In order to evaluate the effectiveness of such areas to protect river dolphins from direct exploitation, prey reduction, and habitat degradation, an understanding of river dolphin movement patterns, including range, rate of movement, and site fidelity, is required.

Knowledge of site fidelity and movement patterns of *Inia* and *Sotalia* has been restricted by the limited spatial and temporal scales of studies. With the exception of information from an ongoing, 12-y long capture and tagging program in the central Brazilian Amazon (da Silva & Martin, 2000; Martin & da Silva, 2004b), all other studies have been of less than 2 y in duration and were conducted in waterways under 185 km long (Trujillo Gonzales, 1994; McGuire, 1995; Hurtado Clavijo, 1996; Leatherwood, 1996; Utreras, 1996; Galindo, 1998; Henningsen, 1998; McGuire & Winemiller, 1998; Flores, 1999; Reeves et al., 1999; Zúñiga, 1999; Aliaga-Rossel, 2000, 2002; Denkinger, 2001).

For long-term investigations of cetaceans in which all or most of the individuals in a population

have been identified, photo-identification techniques can provide insight into home range size, site fidelity, movement patterns, and rates of movement (Würsig & Würsig, 1977; Bain, 1990; Würsig & Jefferson, 1990). Compared to other methods of identifying individual animals, such as tagging (e.g., freeze branding, plastic tags) or tracking (e.g., radio tags, satellite tags), photo-identification is less invasive, generally less expensive, does not require specialized training in animal capture and handling methods, and research permits are often not as difficult to obtain.

As part of a long-term study of river dolphin ecology, photo-identification was used to examine site fidelity and movements of *Inia* and *Sotalia* along a 600-km length of waterways in Peru's Pacaya-Samiria Reserve between 1991 and 2000.

Materials and Methods

Study Area

The study area was located within Peru's Pacaya-Samiria Reserve, 93 km upriver from the city of Iquitos, Department of Loreto, Peru, in the far western Amazon Basin (Figure 1). Classified as a lowland tropical rainforest zone (Lewis et al., 1995), the Reserve is bounded by the Marañón and Ucayali Rivers, which are the parent rivers of the Amazon River. Major tributaries of these rivers are, respectively, the Samiria River (400 km long) and the Pacaya River (380 km long). The Reserve has over 10,000 km of linear waterways, comprised of main stem rivers, tributaries, confluences, channels, and lakes. A protected area since 1940, the Pacaya-Samiria Reserve is the largest reserve in Peru at 2,150,700 ha (INRENA-CTARL 2000).

Field Sampling

Between 1991 and 2000, several studies on river dolphin ecology and conservation were conducted in the Pacaya-Samiria Reserve (Leatherwood, 1996; Henningsen, 1998; Zúñiga, 1999; Leatherwood et al., 2000; McGuire, 2002; McGuire & Aliaga-Rossel, 2007), which offered relatively pristine habitat in which to obtain baseline data for both *Inia* and *Sotalia*. Methods and results described in this paper are from McGuire (2002) and Henningsen (1998), and represent 46 research cruises conducted between 1994 and 2000, with sampling in all years and all seasons. Photo-catalogs created during this time period were supplemented with photo-catalogs derived from 21 dolphin surveys conducted from 1991 through 1993 (Leatherwood, 1996) and 78 dolphin surveys conducted from 1997 to 1998 (Zúñiga, 1999). Data collection consisted of boat-based surveys of dolphins and habitat, photo-identification of individual dolphins, necropsies of dolphins, and interviews with local people. Waterways sampled within the Reserve were the Marañón, Samiria, Yanayacu, Pucate, and Yanaquillo Rivers; the channel of Atun Caño; and the oxbow lakes of Atun Cocha, San Pablo de Tipishca, and Tipishca del Samiria (Figure 1). Photographs were taken from moving and stationary survey vessels, and photographer eye-heights ranged between 2 to 7 m above the waterline. Skiffs in which the photographer essentially stood or sat at water level were also used. Survey vessels varied according to researcher, time of year, and habitat type (Leatherwood, 1996; Henningsen, 1998; McGuire, 2002). Although photo-identification was attempted for all dolphin sightings, effort was concentrated in the confluences because these areas were preferred river dolphin habitat (Magnusson et al., 1980; McGuire & Winemiller, 1998; Martin & da Silva, 2004b). Photo-identification was opportunistic during ship-based survey transects of lakes and rivers; during these surveys, species, group size, age composition, and GPS position were recorded for each dolphin sighting, and results were used to determine encounter rates and to estimate population size (see Henningsen, 1998, and McGuire, 2002, for survey details).

Cameras used were a Leica R4 and R5 with a motor drive and Tamron 80-200 zoom lens (1994 to 1995), a Canon AV-1 with a Tamron SP 60-300 zoom lens (1996 to 1998), and a Nikon N6006 AF with motor drive and Tokina 100-300 zoom lens (1999 to 2000). Film speed (50, 100, 200, and 400 ASA), type (slides and prints), and brand varied. Color film was used for all images to capture color patterns of dolphins.

Individual dolphins were differentiated on the basis of cuts and nicks to the dorsal fin and back, pigmentation patterns on the back and head, scars, tooth-rake marks, and abnormally shaped beaks. Although the color of individual dolphins was sometimes observed to change over hours and days, the patterns of the pigmentation did not change; this phenomenon also has been noted in previous studies (Trujillo Gonzales, 1994; McGuire, 1995; Zúñiga, 1999).

Over 9,000 images were taken between 1991 and 2000. Images were examined with an 8-power optical loupe and were classified as good, fair, or poor, based on quality of the photography and body exposure of the animal. Good images were those in which the animal was close enough and the image was sufficiently focused to permit identification of unique characteristics (where they existed); fair images were those in which only very conspicuous marks could be distinguished; and in poor images, most markings were impossible to detect due to out-of-focus images, poor contrast, or

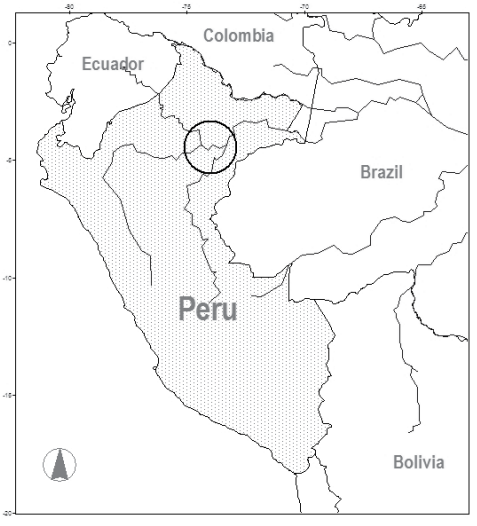

Figure 1. Map of the study area (in white): Pacaya-Samiria National Reserve, Peru, western Amazon Basin

if too little of the animal's body was above water. In general, photos were more useful the closer the dolphin was to the photographer. In order to compare standardized views of natural marks, only profiles in which the animal was parallel to the photographer were used, with the exceptions of images of one dolphin easily identified by a ring of pigmentation around the blowhole and another by an abnormal beak. Suites of images were used to designate type specimens (Würsig & Jefferson, 1990), and drawings were made by hand of the composite features of an individual. Images were omitted from analyses if there was doubt about a match. Resighting information from good and fair images was used to create chronological location maps for resighted individuals. Images were compared with photo-catalogs from Leatherwood (1996) and Zúñiga (1999). Range maps and sighting histories were created from the compiled data, which spanned the period 1991 to 2000.

Results

Identification and Resighting Histories

Seventy-two *Inia* and seven *Sotalia* were identified within the study area, and 25 *Inia* and one *Sotalia* were resighted (Table 1). Mean minimum population estimates were derived from counts of dolphins seen during ship-based line transects, including mid-line transects of rivers and zigzag transects of lakes (Leatherwood, 1996; Henningsen, 1998; Leatherwood et al., 2000; McGuire, 2002). These transects yielded minimum population estimates of 207 *Inia* (± 24.1 SE) and 138 *Sotalia* (± 2.6 SE), indicating that an estimated 35% of *Inia* and 5% of *Sotalia* were identified photographically and that 12% of *Inia* and 1% of *Sotalia* were resighted.

Individual sighting histories ranged from 1 d to 7.6 y (Table 1). The highest resighting rate was 24 times, while 40% of identified dolphins were only resighted once. In general, the more distinctive and conspicuous the identifying characteristic,

Table 1. Resighting records of *Inia* and *Sotalia* identified between 1991 and 2000 in the Pacaya-Samiria Reserve

Identified dolphin	Number of times sighted	Span of sightings (mo)	Maximum range (km)	River system
Inia CDO	24	91	160	Samiria[1]
Inia FTN	19	76	220	Samiria[1]
Inia FZY	9	51	20	Samiria[1*]
Inia GR	5	51	69	Samiria[1]
Inia TN	6	37	160	Samiria[1]
Inia FB	5	35	22	Samiria[1]
Inia BTN	8	33	90	Samiria[1]
Inia BNI	4	7	85	Samiria
Inia SCH	2	29	10	Samiria[1]
Inia CST	2	28	20	Samiria[1*]
Inia LHB	3	22	69	Samiria[1]
Inia TB	2	19	20	Samiria[1*]
Inia BCD	3	19	66	Samiria[1]
Inia RHB	3	19	94	Samiria
Inia TBN	3	18	20	Samiria[1*]
Inia TBR	3	16	20	Samiria[1]
Inia RRN	2	6	20	Samiria[1]
Inia BBL	2	3	10	Samiria[1*]
Inia SPL	2	3	20	Samiria[1]
Inia MGL	2	1 d	20	Samiria[1*]
Inia FTO	13	41	NA	Yanayacu
Inia X	2	35	NA	Yanayacu
Inia PS	2	11	NA	Yanayacu
Inia RBS	3	10	NA	Yanayacu
Inia GS	2	6	NA	Yanayacu
Sotalia WHT	4	6	130	Samiria

[1]Indicates seen at least once within the oxbow lake Tipishca del Samiria

*Indicates individual never seen outside of the Tipishca del Samiria

the higher the resight rate. For example, the dolphin CDO had the most conspicuous identifying mark, the highest resighting rate, and one of the longest sighting histories. This animal had a large V-shaped chunk missing from its back just in front of the peak of the dorsal crest, which may have been made by a boat propeller. This mark was not only distinctive, but it was on a part of the body that could still be seen when the animal was mostly submerged. Of the 4,000 images taken by McGuire (2002), 10% of the images were classified as good or fair. The majority of images were classified as poor because too little of the dolphin's body was visible above the water. Thirty percent of all images which were considered good or fair were of an animal with one or more visible distinguishing characteristics (i.e., 3% of all images taken were used for photo-identification).

Range and Site Fidelity

Identified dolphins were not observed to move between the three sampled blackwater tributaries of the Marañón River (i.e., the Yanayacu River, San Pablo de Tipishca, and the Samiria River System; 30, 40, and 70 km apart, respectively) but, instead, were always observed within the same tributary system. Twenty *Inia* were resighted in the Samiria River System (i.e., the Samiria River, Tipishca del Samiria, Uiuri Caño, Uiuri Cocha, and Atun Caño), and five *Inia* were resighted at the Yanayacu/Marañón Confluence. Two dolphins were identified at the San Pablo de Tipishca del Samiria/Marañón Confluence, but these animals were never resighted. Ranges were calculated for dolphins resighted in the Samiria River System (Table 1) but not for dolphins resighted in the Yanayacu/Marañón Confluence because photo-identification effort did not extend up the Yanayacu River.

In the Samiria River System, the maximum *Inia* range (defined as the river distance between the two most extreme sighting locations) was 220 km (Table 1), with a mean range of 60.8 km (± 61.05 SD). Ninety percent of all *Inia* resighted in the Samiria River System were seen in the same oxbow lake, Tipishca del Samiria, at least once, and 33% of dolphins resighted in the lake were never seen outside of the lake. The mean range of those *Inia* in the Samiria River System whose sighting histories were not limited to the Tipishca del Samiria was 112.4 km (± 72.11 SD). The mean range of the survey vessel within the Samiria River System was 138 km/monthly survey, with a maximum range of 388 km.

Rates of Movement

Based on photo-identification, the greatest rate of movement for *Inia* was 120 km in 2 d (Table 2), which corresponded to 60 km/d, assuming a constant rate of travel. The survey vessel never traveled more than 97 km/d, however; therefore, *Inia* travel rates > 97 km/d would not have been detected. The mean rate of movement for *Inia* was 14.5 km/d. The resighted *Sotalia* was observed to travel a distance of 56 km during a 9-h period.

Discussion

Range and Site Fidelity

Maximum (220 km) and mean (61 km) ranges of identified *Inia* within the Reserve were greater than reported ranges of *Inia* from other study areas. *Inia* marked and tracked in the Brazilian Amazon (Martin & da Silva, 2004b) commonly had daily movements of 20 km, although movements of 100 km also occurred, while some animals were observed to remain for weeks in the same lakes without moving out of a 1 km^2 area. There are

Table 2. Range and rates of travel of *Inia* identified between 1991 and 2000 in the Pacaya-Samiria, based on resightings which occurred within a week's time

Identified *Inia*	No. days between sightings	Maximum distance between sightings (km)	Distance traveled per day in km (assuming constant rate of travel)
CDO	2	120	60
CDO	1	50	50
TN	2	92	46
FTN	3	75	25
GNI	1	25	25
FTN	6	66	11
CDO	1	10	10
LRHB	1	10	10
FTN	4	0	0
RBS	1	0	0

anecdotal reports of *Inia* traveling over 1,000 km (T. Henningsen, pers. comm.; Martin & da Silva, 2004b). In Colombia, Hurtado Clavijo (1996) observed *Inia* ranges of 1 to 80 km, with a mean of 19 km. Maximum ranges of 150 km were recorded for *Inia* in Ecuador (Denkinger, 2001), and Aliaga-Rossel (2000, 2002) noted a maximum range of 60 km in Bolivia. In Venezuela, a maximum range for *Inia* was 10 km, but it was limited by the range of the small study area (McGuire, 1995; McGuire & Winemiller, 1998). Because the maximum reported ranges for *Inia* are reported within the limits of study areas, it cannot be concluded that the ranges for *Inia* in the Pacaya-Samiria Reserve are necessarily larger than ranges of *Inia* found in other regions. Hypotheses to explain differences in range size, such as differences in prey availability, will be possible only after comparisons are made of river dolphin ranges among study areas of similar size.

To our knowledge, this study reports the first published range for riverine *Sotalia*, although the sample size is small. *Sotalia* were more difficult to identify than *Inia* because they avoided boats, did not remain long in any one area, surfaced quickly and unpredictably, and were not as distinctly marked. Other researchers have reported similar difficulties with photo-identification of *Sotalia* (Trujillo Gonzales, 1994; Zúñiga, 1999; Edwards & Schnell, 2001).

Dolphins identified within the Samiria River System and the Yanayacu/Marañón Confluence were never observed outside of their respective river systems. This may indicate site fidelity to a river system, although increased sampling efforts in more locations outside the river system are needed. Martin & da Silva (2004b) found significant movements of tagged animals between adjacent river systems in Brazil. Denkinger (2001) also observed identified *Inia* traveling between blackwater river systems in Ecuador.

The oxbow lake of Tipishca del Samiria appeared to be an important habitat for *Inia*. Zúñiga's (1999) high rate of new photo-identifications of *Inia* throughout a yearlong study in this lake led her to conclude that the Tipishca del Samiria had a local population with moderate immigration and emigration. The present study found that 33% of all dolphins identified in the Samiria River System were never observed outside of this oxbow lake, 53% of all identified *Inia* in the Samiria River System were seen only in the lake and its vicinity (< 5 km from the lake), and 90% of all identified *Inia* in the Samiria River System were seen in this lake at least once. Taken together with the data from Zúñiga (1999), these numbers suggest that the lake has residents and transients. These results are consistent with other studies on *Inia*. Martin & da Silva (2004b) distinguished residents, partial residents, and transients in the oxbow lake in Brazil. In Venezuela, McGuire (1995) reported that the majority of photo-identifications of *Inia* encountered in an oxbow lake were never resighted in adjacent waterways. Sexual segregation of *Inia* according to season and habitat, shown to exist in Brazil (Martin & da Silva, 2004a), may be related to residency and movement patterns in the Pacaya-Samiria Reserve, but the data necessary to evaluate this do not currently exist.

We were unable to compare range, rates of travel, and site fidelity among various age and sex classes of *Inia* or *Sotalia*. Photo-identification studies of river dolphins have not provided information on the sex or age of individual dolphins (Trujillo Gonzales, 1994; McGuire, 1995, 2002; Leatherwood, 1996; Henningsen, 1998; McGuire & Winemiller, 1998; Flores, 1999; Zúñiga, 1999; Aliaga-Rossel, 2000, 2002; Denkinger, 2001). We were unable to determine sex nor were we able to identify individual juveniles and calves of *Inia* or *Sotalia* as these age classes were uniformly colored and lacked distinctive marks (McGuire & Aliaga-Rossel, 2007). We are also unaware of any other researchers who have successfully done so. None of the animals we identified were observed in close proximity to neonates or calves. Martin & da Silva (2004a) reported that "experience in the field (with marked *Inia*) indicates that adult females, especially those with small calves, are less likely to expose their dorsal fins when surfacing, and are therefore less likely to be identified when present" (p. 303), which suggests that photo-identification of this demographic is problematic.

Rates of Movement

Inia frequently moved 40 to 60 km within a 24-h period, although other individuals remained in the same location for several days. These relatively high rates of travel occurred during high and receding water levels, although sample size was insufficient to detect any trends between seasons and distance traveled. Sampling rarely occurred at the same location on consecutive days; therefore, observations are biased towards dolphins that moved and against those with strong site fidelity.

Henningsen (1998) observed a maximum rate of travel of 56 km/12 h by *Sotalia*. McGuire (2002) did not successfully identify *Sotalia*; however, her general impression from line-transect surveys was that they traveled among locations much more frequently than *Inia*.

Length of Sighting Histories

Sighting histories for identified dolphins in the study area varied from 1 d to 7.6 y. There is little

information regarding the duration of site fidelity of river dolphins because all but the work of Trujillo Gonzales (1994), Denkinger (2001), and the present study consisted of photo-identification studies lasting one year or less (McGuire, 1995; Hurtado Clavijo, 1996; Utreras, 1996; Galindo, 1998; McGuire & Winemiller, 1998; Zúñiga, 1999; Aliaga-Rossel, 2000), and all had records of *Inia* sighting histories lasting the length of the study. Tagged and branded individual *Inia* in Brazil have been resighted throughout the last 12 y of an ongoing study (Dr. A. R. Martin, pers. comm., British Antarctic Survey, High Cross, Madingley Road, Cambridge CB3 CET, UK).

Application of Photo-Identification to River Dolphins

Field efforts would likely have yielded more insight into movement patterns and sight fidelity if photo-identification had been a more robust technique for identifying and resighting individual river dolphins. The use of photo-identification to study river dolphins is limited due to the behavioral, morphological, and ecological characteristics of these animals.

In this study, the most distinctively marked animals had the highest resight rates and the longest resighting histories. Wounds from human interactions (such as fishing nets, machetes, boat propellers, and drop-traps for large fish) resulted in the most reliable marks for identification. Dolphins with less distinctive or inconspicuous marks were likely often missed, and therefore a low number of resights, or even lack of resights, does not necessarily mean that an animal was not in the study area. In addition, some animals had distinctive identifying marks, but the marks were not usually visible above the water, and their presence in the study area is probably underrepresented. The low surfacing profile (e.g., generally only the upper melon, blowhole, and upper dorsal crest are visible for *Inia*) makes photo-identification of this species difficult, along with the fact that *Inia* have a low dorsal crest rather than a dorsal fin. For example, one identified dolphin (FB) had a broken and twisted beak, and distinctive pigmentation patterns along its back and sides. This dolphin was initially classified as two different animals because the back and the beak were never clearly visible at the same time. It was only after 3 y of resights that this animal was observed and photographed lifting its beak out of the water and simultaneously arching its back.

Other studies have reported that rates of capture and recapture of river dolphins with photo-identification are generally low (1 to 12 %), especially when compared to the mean population sizes estimated with transects (McGuire, 1995, 2002; Henningsen, 1998; McGuire & Winemiller, 1998; Aliaga-Rossel, 2000). These results beg the question of whether a smaller sampling area and/or increased sampling effort would have resulted in higher identification and/or resight rates. Zúñiga (1999) had an intensive photo-identification study of *Inia* and *Sotalia*, with daily effort for almost a year in one lake of the Pacaya-Samiria Reserve, yet only one individual of each species was observed more than four times

It is worth noting that photo-identification has not been used in the longest continual study of *Inia* and *Sotalia* in the wild; since 1994, da Silva & Martin (2000) captured over 400 animals and marked and fitted them with freeze brands, plastic tags, radio tags, and satellite tags but have not used photo-identification in their study area in Brazil. The authors believed the opacity of the water, the cryptic surfacing patterns of *Inia*, and the lack of distinctive marks would not provide adequate photo-identification analysis.

Since the time of our study, digital photography has since become more widespread and affordable, which may be a promising development for photo-identification of river dolphins. Digital video cameras with screen image capture capabilities may be useful for photographing rapidly moving *Sotalia*. Even so, better technology still will not solve the inherent problems of photographing river dolphins: low surfacing profiles, unpredictable surfacing behavior, indistinct marks, avoidance of boats, and turbid water.

Application for Conservation

Due to small sample sizes resulting from low rates of identification and resighting, and the inability to determine sex or identify calves, this study is unable to make inferences regarding differences in movement patterns and site fidelity with respect to age class, sex, habitat type, or season. It does provide data which suggest that when evaluating the ability of protected areas to protect river dolphins, conservation planners should consider that river dolphins may live many years in an area, that river dolphins may not move between adjacent river systems, that oxbow lakes are likely to be important dolphin habitats, that within a river system some *Inia* may be residents and others transients, and that *Inia* and *Sotalia* have larger potential ranges with greater rates of movement than previously known.

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