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The catfish, *Rhinelepis aspera* (Teleostei; Loricariidae), in the Guaíra region of the Paraná River: an example of population estimation from catch-effort and tagging data when emigration and immigration are high

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Abstract

Using the Leslie model, an estimate was made of the stock of the loricariid catfish, *Rhinelepis aspera*, in the fishing grounds in the Guaíra region of the Paraná River. The method was based on catch-effort and mark–recapture data collected over a 90 day period in 1986. The estimated initial population size, based on catch-effort, was 734 806 catfish with a biomass of 580 297 kg. During the experiment 2.372 million catfish entered the fishing area and 1.892 million catfish emigrated from it. A Petersen type estimate, based on the recapture ratio of tagged fish, was 812 359 catfish at the beginning of the experiment.

Keywords: Rhinelepis aspera; Population estimation; Tagging; Modelling

1. Introduction

The loricariid catfish, called 'cascudo-preto', *Rhinelepis aspera* (Agassiz, 1829), supports an important commercial fishery in the Guaíra region of the Paraná River with a daily catch of almost 1 metric ton during the 1984 fishing season.

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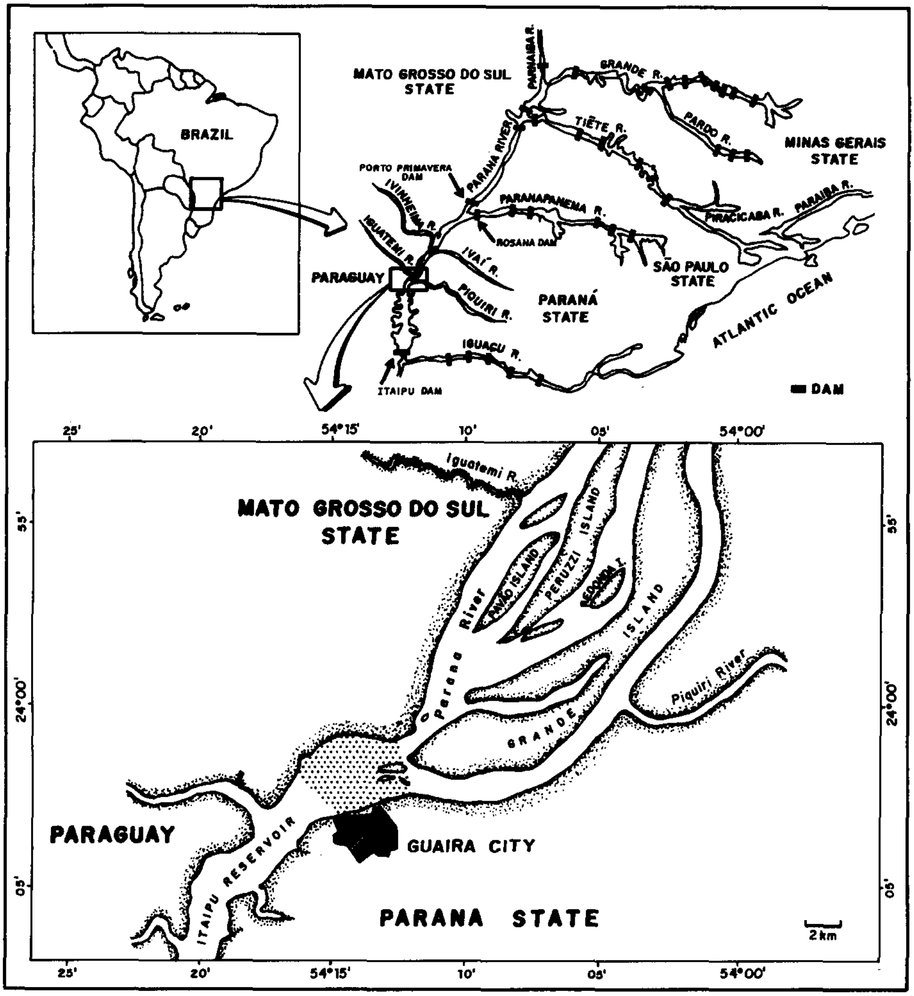

Fig. 1. The Guaíra region of the Paraná River. The main fishing grounds are represented by the shaded area with dashed lines.

The total catch of this species occupied the fifth place for the area between the Itaipu Dam and the Piquiri River, with a mean annual catch of 64 metric tons during 1987–1991 (Fundação Universidade Estadual de Maringá/Itaipu Binacional, 1990). The spawning season extends from December to February, during which time this species undertakes a long migration to upstream of the Paraná River, the Paranapanema River or up to the Rosana Dam. All eggs from a single female are laid in one batch, and the mean fecundity per female is 47 370 (Agostinho et al., 1987). The minimum size at spawning is 23.5 cm total length (TL) and the maximum size caught commercially is 54 cm (Agostinho et al., 1991).

Adult *Rhinelepis aspera* are sedentary and concentrated in a restricted region, from the head of the former Sete Quedas falls to south of the Grande Island, where they form dense aggregations of foraging schools on the rocky floor of the Paraná River (Fig. 1). However, no juveniles are caught in this area.

In the Paraná River basin many regional stocks of *Rhinelepis aspera* have been known, but recently they have not been found. It was the most important species in the Piracicaba River fisheries (50%) in 1959 (Monteiro, 1963, 1965) and in the Paranapanema River in 1980 (Agostinho et al., 1987). Now it is absent in the commercial catches in these rivers, probably because of pollution, impoundment and overfishing.

Upstream of the Paraná River, commercial fishing of this catfish takes place only in the Guaira region, except during the spawning season when migrating schools are caught sporadically at some other places. The spawning season coincides with the flood season (from December to March), when the water in most parts of the Guaira region becomes too deep to use the cast net. The commercial fishing of catfish is by monofilament cast net with a height of 2 m and a mesh aperture of 12 cm. Due to the small mesh size catfish of all size classes are caught, ranging from 19.5 to 49.4 cm TL, encountered on the river bottom. There are about 80 professional fishermen using this fishing gear in the area. Because of water turbidity, the fishermen cannot detect fish schools, so they cast the net randomly over the water surface from a small anchored boat.

Estimates are presented of the stock biomass of *Rhinelepis aspera* in the Paraná River, Guaíra region, in 1986 together with the rates of fishing, immigration and emigration.

2. Materials and methods

2.1. Surveyed area

The Paraná River is the second major river basin in South America and consists of many wide braided channels with low gradient, which form a large flooded area of lowland, or large islands with semi-flooded areas. The surveyed area extends for about 7 km in the transition zone between the Itaipu Dam and upstream of the Paraná River, including the entire extension above the Sete Quedas falls before the formation of the Itaipu Dam. The surveyed area, which is under the influence of dammed water, has nevertheless a strong stream with flat rocky bottom and some flat areas with sandy bottom.

2.2. Catch-effort and tagging data

Fish for tagging were caught by a cast net from a small boat with one or two fishermen. A total of 2695 specimens were caught by fishermen during the period 20–23 June 1986, and were marked with a dart tag at the base of the posterior end of the dorsal fin. Tagged fish were measured (total length, TL) and released close to the fishing area. After 5 days of release of the last fish, the daily catch,

Table 1
Total catch, fishing effort, tags recaptured, CPUE total and tagged fish, cumulative catch total and tagged fish, and ratios of recaptured tagged fish for 15 day periods of the loricariid catfish *Rhinelepis aspera* in the Guaíra region, Paraná River

Period	Total catch (c_t)	Effort (f_t)	Tags recaptured (c'_t)	CPUE (c_t/f_t)	Cumulative catch (K_t)	CPUE (c'_t/f_t)	Cumulative catch K'_t	Recapture ratio (m/n or c'_t/c_t)
1	15473	431	53	35.9	7736	0.12297	26.5	0.00343
2	17714	389	27	45.5	24330	0.06941	66.5	0.00152
3	20837	416	31	50.1	43606	0.07452	95.5	0.00149
4	19650	410	13	47.9	63849	0.03171	117.5	0.00066
5	22580	391	15	57.8	84964	0.03836	131.5	0.00066
6	22513	430	2	52.4	107510	0.00465	140.0	0.00009
Σ	118767	2467	141	289.6	331996		577.5	

fishing effort (i.e. number of fisherman-days) and the number of recaptured marked fish were recorded over 90 days. These daily data were grouped into six periods of 15 days (Table 1).

2.3. Catch-effort estimate

The catch-effort data were analysed using the method of Leslie and Davis (1939) and DeLury (1947, 1951). This involves plotting catch per unit effort against cumulative catch over a period of time as defined by the following symbols:

N_0, original population size at the beginning of fishing season.

N_t, mean population surviving during time interval t.

c_t, catch taken during time interval t.

K_t, cumulative catch of the start of interval t plus half of that taken during the interval, or,

$$K_t = \sum_{n=1}^{t-1} c_n + (c_t/2)$$

q, catchability rate (k of DeLury) or the fraction of the population taken by one unit of fishing effort.

f_t, fishing effort during time interval t.

C_t, catch per unit effort (CPUE) during time interval t, or, $C_t = c_t/f_t$.

By definition, CPUE is equal to catchability multiplied by mean population present during the time interval:

$$C_t = qN_t \quad (1)$$

and

$$N_t = N_0 - K_t \quad (2)$$

From Eqs. (1) and (2):

$$C_t = qN_0 - qK_t \quad (3)$$

This equation requires that three assumptions are satisfied: (1) the population is closed; (2) fishing removal accounts for all changes in stock biomass and the natural mortality, recruitment and growth during the experimental period have a negligible effect on the population; (3) the catchability is constant and all individuals have an equal chance to be captured by unit fishing effort.

In the case of a semi-closed population, the catchability will be affected by immigration, emigration, or both, of fish. To correct this distortion on catchability, mark–recapture data were used (Ketchen, 1953).

As the trends in CPUE (C'_t) of tagged fish are related to the cumulative catch (K'_t) of tagged fish, the relation between two variables is:

$$C'_t = q'N'_0 - q'K'_t \quad (4)$$

where q' is apparent catchability of tagged fish and N'_0 is the population of tagged fish when $t=0$. Because the number of tagged fish (T) is known beforehand, the estimate of N'_0 of Eq. (4) must match with known T. Thus, the N'_0 value can be substituted by T to obtain the true catchability q'' of the tagged fish using the equation:

$$q'' = q'N'_0/T \quad (5)$$

As the estimate of catchability of catch-effort data of Eq. (3) is influenced by the effects of emigration and immigration, the real estimate of original population (N''_0) can be made using the true catchability obtained in Eq. (5):

$$N''_0 = qN_0/q'' \quad (6)$$

2.4. Petersen method with tagging data

To obtain another estimate of population size, the mark–recapture data were analysed using the Petersen method, modified by Parker (1955). After marking, an immigration of new fish in the surveyed area will dilute the marked fish, thus the ratio of recaptures to total sample (m_t/n_t) tends to fall off with time (t). If this fraction is plotted against time and a line fitted, the intercept at $t=0$ is an estimate of m_0/n_0 at the time of marking. Estimate of initial population size can be obtained by dividing the number of tagged fish (T) by m_0/n_0. An estimate of error of the y-intercept (m_0/n_0) can be made by calculating the standard deviation from the regression line and the standard error of the intercept at $t=0$.

3. Results

3.1. Estimate from catch-effort data

During the experiment 118 767 catfish were caught by an average fishing effort of 28 fishermen per day (Table 1). The mean size and weight of catfish were 35.9

cm and 790 g, respectively. Average CPUEs per period of 15 days were plotted against the cumulative removals (K_t) (Fig. 2) and the least-squares regression equation calculated is:

$$C_t = 39.2701 + 0.000162K_t \quad (7)$$

with standard errors of the slope and intercept equal to 0.0000549 and 4.602, respectively. There was no decline of regression line relating two variables, suggesting the strong influence of immigration of catfish in the fishing area during the experiment. The 95% confidence limits of the estimate of constant *a* are:

$$34.05 < qN_0 < 44.59$$

3.2. Use of catch-effort data in conjunction with tagging data

Of 2695 tagged fish released before the experiment, 141 were recaptured. The average CPUEs (C'_t) of tagged fish per 15 day period were plotted against the cumulative catch of tagged fish (K'_t) (Fig. 3). The least squares regression equation was:

$$C'_t = 0.14403 - 0.000905K'_t \quad (8)$$

with standard errors of the slope and intercept equal to 0.000153 and 0.14813, respectively. The apparent catchability q' was 0.000905 and estimate of N'_0 was

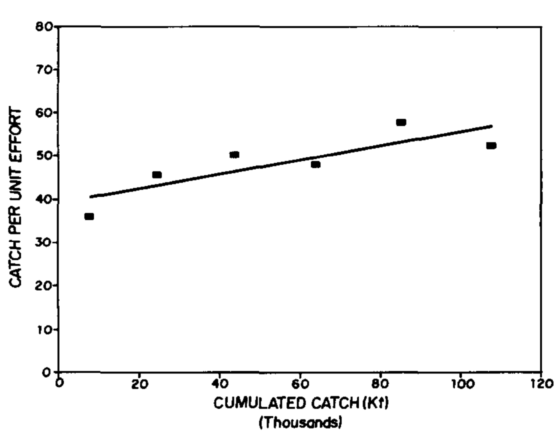

Fig. 2. Relationship between the catch per unit effort (C_t) and cumulative catch (K_t) of the loricariid catfish in the Guaíra region, 1986.

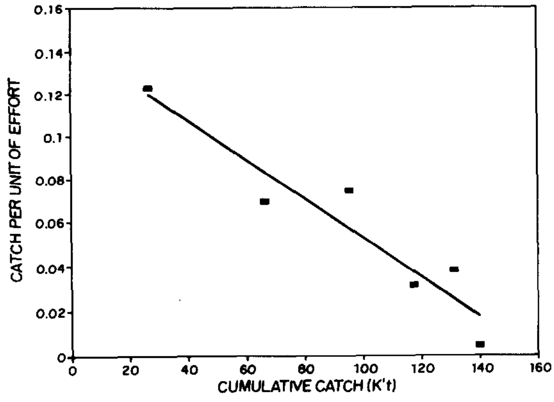

Fig. 3. Leslie model applied to the mark–recapture data of the loricariid catfish. Each point represents the mean CPUE (C'_t) for a 15 day period.

159.17. As there was no immigration of tagged fish, the catchability obtained in this regression was influenced only by emigration. Substituting the N'_0 by the number of tagged fish (T) gave the true catchability:

$$q''=q'N'_0/T=0.00005344$$

The initial population size of the total fish was now calculated from Eq. (7), by dividing N_0 by q'':

$$N''_0=qN_0/q''=39.27/0.00005344=734806$$

Using the estimate of standard error of the y-intercept of the regression, the 95% confidence limits of population size are obtained:

$$637715<N''_0<833052$$

To estimate the population biomass, 2775 catfish were measured and a size frequency distribution obtained (Table 2). Using the length/weight relationship (Agostinho et al., 1991), the weight of each size class was calculated and the total population biomass (B_0) 580 297 kg was obtained.

3.3. Estimate of emigration and immigration

The rates of emigration and immigration can be computed using q-values obtained above (Ketchen, 1953). The rate of emigration is the difference between the apparent catchability of tagged fish (q') and the true catchability (q''):

$$q'-q''=0.0009048-0.0000534=0.0008514$$

The rate of immigration is measured by the difference between the apparent catchability (q') of the tagged fish and the catchability with effects of both emigration and immigration (q):

Table 2
Size frequency distribution and biomass estimate of the loricariid catfish *Rhinelepis aspera* in the Guaíra region, Paraná River

Size class (cm)	Frequency (%)	No. of fish measured	Mean weight (g)	Total number of catfish by class	Weight by size class (kg)
19.5	0.04	1	119.4	265	31.62
20.8	0.00	0	144.1	0	0.00
22.1	0.04	1	171.9	265	45.52
23.4	0.25	7	203.1	1854	376.50
24.7	0.11	3	237.9	794	188.98
26.0	0.76	21	276.4	5561	1537.18
27.3	1.73	48	318.9	12710	4053.65
28.6	2.27	63	365.6	16682	6098.48
29.9	3.93	109	416.6	28863	12022.78
31.2	5.15	143	472.1	37866	17875.12
32.5	7.35	204	532.3	54018	28754.35
33.8	8.40	233	597.5	61697	36862.36
35.1	9.91	275	667.7	72819	48624.57
36.4	10.56	293	743.3	77585	57671.51
37.7	10.77	299	824.4	79174	65272.36
39.0	11.57	321	911.2	84999	77451.25
40.3	11.06	307	1003.9	81292	81606.50
41.6	7.42	206	1102.6	54548	60145.33
42.9	5.01	139	1207.6	36806	44449.08
44.2	2.38	66	1319.1	17476	23053.82
45.5	0.97	27	1437.3	7149	10275.85
46.8	0.18	5	1562.3	1324	2068.45
48.1	0.11	3	1694.4	794	1345.97
49.4	0.04	1	1833.7	265	485.54
Average = 35.9		$\Sigma = 2775$		$N_0 = 734.806$	$B_0 = 580297.00$

$$q' - q = 0.0009048 + 0.0001620 = 0.0010668$$

The rates of fishing (p), emigration (j) and immigration (h) were obtained:

$$p = Eq'' = 2467 \times 0.00005534 = 0.13184$$

$$j = E(q' - q'') = 2467 \times 0.0008514 = 2.1004$$

$$h = E(q' - q) = 2467 \times 0.0010668 = 2.6331$$

where E is total effort ($\Sigma_t ft$).

The average number of fish in the population during the period is given by: $N = (\text{total catch})/p = 118767/0.13184 = 900818$ fish or a biomass of 711 401 kg.

The numbers of emigrants and immigrants in the fishing area are given by:

$$\text{Emigrants} = jN = 900818 \times 2.1004 = 1892098 \text{ fish}$$

$$\text{Immigrants} = hN = 900818 \times 2.6331 = 2371916 \text{ fish}$$

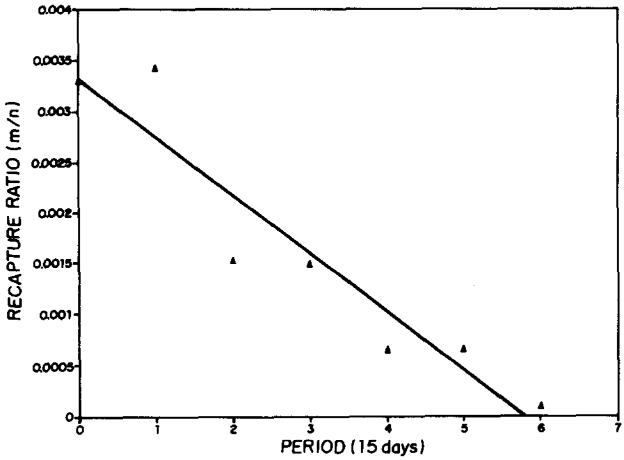

Fig. 4. Parker method applied to the mark–recapture data of the loricariid catfish. The mean recapture ratios of marked catfish (m_t/n_t) for each 15 day period were plotted against time.

Summarizing the results, we can conclude that, at the beginning of the period, the initial population was 734 806 fish, and during the period 1.892 million fish moved out from the area and 2.372 million moved in.

3.4. Estimates from tagging data

Because of immigrations, the ratios of recaptures to total samples decreased during the period. The recapture ratios (m_t/n_t) were plotted against a period of 15 days and a standard regression equation was calculated (Fig. 4):

$$m_t/n_t = 0.033174 - 0.00057t$$

with standard errors of the slope and intercept equal to 0.000126 and 0.000528, respectively. The y-intercept of this regression is an estimate of original recapture ratio (m_0/n_0) at the beginning of the experiment. The initial population was estimated by the Petersen method:

$$N_0 = T/(m_0/n_0) = 2695/0.0033174 = 812359$$

Estimate of the standard error of the y-intercept was obtained by normal statistical calculation and 95% confidence limits of estimate were obtained:

$$644127 < N_0 < 1099553$$

4. Discussion

Estimate of catchability is perhaps the greatest potential source of error in applying the depletion experiment for population estimation (Ricker, 1975). Many studies have shown that the catchability varies with seasonal changes in environmental conditions (Morgan, 1974b; Morrissy, 1975) or by population size (MacCall, 1975; Pope and Garrod, 1975). Change in catchability produces changes in CPUE, which may conceal any change of population abundance. Using Monte Carlo simulations, Braaten (1969) demonstrated that, in the DeLury estimator, an increase in catchability from a previously constant level produced an increase in the estimate of population size, and a decrease in catchability resulted in a decreased estimate.

Another potential source of error is a change in vulnerability of catch, which may directly affect catchability. In the case of crustacean stocks caught by traps, it is well known that catchability is affected by molting, sex and feeding history (Morgan, 1974a; Morrissy, 1975; Saint-Marie, 1987; Ralston and Tagami, 1992). Change of catchability due to the presence of aggressive dominant species in the fishing area was reported for demersal lutjanid fishes by Polovina (1986). In the case of fishing of *Rhinelepis aspera* in the Guaíra region, the vulnerability seems to be constant because the fishing is done randomly by casting a net on the aggregated foraging schools on the flat rocky river bed.

In the case of short-term variation of catchability observed in the depletion experiment over a short period, this appears in the form of scattered points along the line obtained from the two variables, C'_t and K'_t (Fig. 3). The second assumption of Eq. (3) of the Leslie model is that the natural mortality, recruitment and growth are negligible during the experiment period. Since we used the mark–recapture data to correct influence of the migration during the experiment, we must consider if an influence of natural mortality and growth during the experiment is significant or not. As shown in Table 2, 91% of the fish caught during tagging experiment ranged from 29 to 43 cm (mean size = 36.7 cm TL). Since the minimum size at first spawning is 23.5 cm TL, most of them were full grown adult fish. Thus, we can consider the growth rate during experiment as insignificant.

The natural mortality coefficient can be obtained using the empirical equation of Pauly (1980):

$$\log M = -0.2107 - 0.0824 \log W_\infty + 0.6757 \log K + 0.4687 \log T$$

where W_∞ is asymptotic size, K is growth coefficient of the Von Bertalanffy equation, and T is mean temperature (°C) of the habitat. Using the growth parameters of *Rhinelepis aspera*, i.e. $W_\infty = 5523$ (in g), $K = 0.106$, $T = 23.0$ (°C) (Agostinho et al., 1991), the M value was estimated as 0.2887 per year. Thus, the M value for 90 days is 0.072 or the natural mortality rate of 7%, which can be considered as insignificant.

Another estimate using the Petersen method, modified by Parker (1955), showed the estimate of initial population of N_0 is 812 369.

The difference between the two estimates of initial population size obtained by the Leslie model and the Petersen method is small: 734 806 vs. 812 359. Thus, our estimate of initial biomass of 580 297 kg by the Leslie model in the Guaíra region seems to be reasonable. However, the estimates of emigration and immigration rates show a highly dynamic population size in the area and any reliable estimate of population size must be accompanied by the mark–recapture method to check the effects of migration.

A preliminary estimate of potential yield can be obtained by the equation:

$$\mathrm{MSY} = 0.5 \times M \times B_v$$

where B_v is biomass of virgin stock and M is instantaneous coefficient of natural mortality (Gulland, 1971). IIM was calculated using the empirical equation of Pauly (1980):

$$\log M = -0.2107 - 0.0824 \log W_{\infty} + 0.6757 \log K + 0.4687 \log T$$

where W_{∞} is asymptotic size, K is the growth coefficient of the Von Bertalanffy equation, and T is mean temperature (°C) of the habitat. Using the growth parameters of *Rhinelepis aspera*, i.e. $W_{\infty} = 5523$ (g), $K = 0.106$, $T = 23.0$ (°C) (Agostinho et al., 1991), the M value was estimated as 0.2887.

Using the biomass of 580 297 kg and the natural mortality coefficient of 0.2887, the potential yield of the catfish was estimated: MSY = 83794 kg.

The stock exploited in the Guaíra region is not isolated, but is a part of the entire population inhabiting the upper streams of the Paraná River. Thus, the MSY obtained here does not correspond to the potential yield of the population. However, if we consider that the foraging schools of catfish in the area are constantly coming in and going out, and the rates of immigration and emigration are more or less equilibrated, then we can try, as a first attempt, to estimate how much can be fished out from this area using the Gulland equation.

The total catch of the catfish in the Guaíra region varied from 62 metric tons in 1987 to 26 metric tons in 1993, with the maximum catch of 82 metric tons in 1989 (Agostinho et al., 1995). When compared with these fishing records, our estimate of the potential yield was in good agreement with the maximum catch, suggesting the original assumption is acceptable.

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