Modern Approaches to the Study of Crustacea

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CONSERVATION OF CONTINENTAL COPEPOD CRUSTACEANS

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ABSTRACT

A discussion on the conservation problems of continental copepods from several parts of the world is presented, based on the experience of local experts. The status of some copepod species of concern for the IUCN Red List is evaluated.

I. INTRODUCTION

Freshwater copepods have not attracted much, if any, specific concern from the general conservationist community, nor have many copepodologists yet dealt directly with this aspect of their field. Most of those who have are Europeans: lists of small crustaceans, including copepods, were furnished for parts of Germany by Blab et al. (1977), Herbst (1982), Flössner (1993), Maier (1998), and Maier et al. (1998), for Slovenia by Sket and Brancelj (1992), and for Italy by Pesce (2000). Some species of concern in Europe are large calanoids, inhabitants of temporary ponds, and most of the remainder are stygobiont species with extremely limited known distributions. Outside Europe, lists exist for Australia (Horwitz 1990) and the state of North Carolina, USA (Clamp et al. 1999). Fryer (1972) mentioned the *Schizopera* species-flock in his argument for protection of Lake Tanganyika and the other African Great Lakes. Bayly contributed largely to the first IUCN Red List for copepods, and also (1992a, 1997, 1999) argued strongly in both the scientific and popular literature for preservation of distinctive ephemeral freshwater habitats, including gnammas (solution holes in rock outcrops) in Australia. Danielopol (1992, 1998) argued equally strongly for preservation of groundwater organisms in general. Reid (1994a, 1998) called attention to threats to endemic copepods in the central plateau (cerrado) of Brazil. The 1996 Red List (IUCN 1996) included 118 species of copepods.

In the following sections, several of us discuss conservation problems and some individual species in our respective parts of the world (Bayly, Australia; Pesce, Italy; Rayner, southern Africa; Reid, USA; Rocha, Brazil; Suárez-Morales, Mexico; Ueda, East Asia). All of us

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have contributed to the ongoing assessment of the statuses of copepod species of concern for the IUCN Red List.

A. Salinization: A major threat to the conservation of Australian freshwater Crustacea

Salinization of inland waters has emerged as a major factor in the disappearance of habitat for Australian freshwater crustaceans. This is most striking in the southwest of the continent, especially in the Wheatbelt of Western Australia (Yencken and Wilkinson 2000). This is a region in which all but a small fraction of the original vegetation has been removed. With the clearing of deep-rooted native vegetation, ground-water levels rise and salt is brought to the surface. This is referred to as dryland salinity.

Pinder et al. (2000) drew attention to the way in which fresh waters associated with granite outcrops may play an increasingly important conservation role as the Wheatbelt becomes more saline over the next few decades. Among the Copepoda, salinization in Western Australia may be regarded as a threat to species as *Boeckella geniculata* (vulnerable) and *B. shieli* (critically endangered) (IUCN 1996).

The Murray-Darling Basin in eastern Australia is another region that is beset with salinization. Here, there are both dryland and irrigation-induced salinity problems (Yencken and Wilkinson 2000). Among the copepods, species such as *Calamoecia australica*, which is known from only four localities in western Victoria (Bayly 1992b), are threatened by rising salinity.

The conservation status of Australian freshwater Crustacea in general, was well summarized by Horwitz (1990), who also dealt with threatening processes other than increased salinity.

Draining of coastal lagoons and swamps may threaten certain species such as the vulnerable calanoids *Boeckella nyoraensis* and *B. propinqua*, for which this type of habitat is important. *Boeckella nyoraensis* is known only from coastal localities in Victoria and Tasmania (Bayly 1992b).

B. Threatened groundwater copepods of Italy

In recent years, pollution of subterranean aquifers has become a serious problem in several Italian regions and, in spite of their remarkable scientific and economical importance, underground fresh and coastal biological resources of the country are declining at a very fast rate. Several forces are swiftly producing impoverishment or disappearance of aquatic communities with great economic and scientific value. These include the intrusive proliferation of agriculture and pastoral activities, chemical manufacturers, and petroleum refineries which discharge their waste into large and small aquatic reservoirs of the country. There are also high levels of pollution along the Mediterranean coasts, particularly those related to smaller basins such as the Adriatic and Ionian Seas, as well as pollution of coastal caves, including anchialine caves.

At present, the most endangered aquifers are in the Po, Arno, and Tevere river basins, the northeastern karst region, and the karst of southern Italy (Salentine Peninsula), Sicily, and Sardinia. In these regions the karstic biota, phreatic habitats, springs, and caves are particularly threatened, and detailed conservation measures are necessary for their protection and for assessing preservation priorities: "Buso della Rana" (Vicenza, northern Italy); the Mugnone River basin (Tuscany); the Pescara springs (L'Aquila, central Italy); "Grotta di Stiffe" Cave (L'Aquila, central Italy); "Grotta dell'Arco" Cave (Rome, central Italy); "Grotta di Pertosa" and "Grotta di Castelcività" Caves (Salerno, southern Italy); "Grotta di S. Pietro", "Grotta di Nettuno," and "Grotta su Coloru" Caves (Sardinia); anchialine systems of Porto Palo (Sicily); "Zinzulusa," "Buco dei Diavoli," and "L'Abisso" Caves (southern Italy); and anchialine systems along the Adriatic coast (southern Italy).

These ecosystems are variously threatened by tourism, agriculture and urbanization, proximity to hydro-electric construction, invasion of alien species, and the carelessness of cavers who often are unaware of the presence of rare, often the only known population of particular species, in these environments. In some cases, the impact of stochastic events on habitat can affect populations or subpopulations with a limited distribution in the same areas.

Locally, the tunnels recently excavated under Gran Sasso Mountain in the central Apennines are causing the lowering of a rich phreatic watertable complex and consequently the impoverishment of the surrounding small springs and their remarkable fauna, which includes several interesting rare and endemic species. Unevaluated and extensive sedimentation and landslips in northwestern and southern Italy, resulting from dams and hydroelectric reservoirs, have disturbed and continue to disturb large areas as well as the local ecosystems and fauna.

As an example of present threats to the Italian subterranean ecosystems and fauna, Zinzulusa Cave has been recently included in the 'Ten Most Endangered Karst Communities for 1999' by the Karst Water Institute. Although this cave probably harbors the most rich and diverse cave animal fauna in Europe (more than 60 stygobitic or stygophilic taxa, most of them endemic and of ancient lineage), it is at present seriously polluted from urban discharge. Water also threatens the cave, as do tourists who litter and destroy natural formations, mainly near the cave entrance. Moreover, guano mining in the past removed an already limited energy resource for the communities living in this cave. The fauna of this extraordinary cave is certainly vulnerable, and its protection requires habitat preservation as well as conservation of the associated epigean habitat, since, as in most karstic situations, protection of surface environments may be the key to the conservation of groundwater ecosystems.

Unfortunately, most subterranean fauna is not taken into account in the existing laws affecting environmental protection in Italy. Moreover, the relevant Red Lists are in great need of updating and revision.

As regards copepods, of the more than 150 subterranean species and subspecies presently known from Italy, only 37 could be classified as threatened in that country. Most of these are stygobitic or eustygophilic taxa, of remarkable scientific interest, and belong to different IUCN categories; most, on account of the restriction of their area or the few known localities, fit Red List category VU D (Vulnerable, restricted area). But this number is certainly a minimum estimate, since more taxa could be added to the list in the categories "Data deficient" or "Near Threatened", since there are no adequate data to assess their risk of extinction, or they do not qualify as conservation-dependent, but are close to qualifying as vulnerable. Therefore, it is imperative to know the present status of these taxa, obtain more information to determine their appropriate listing, and to implement necessary and opportune studies.

C. Some ephemeral and semi-terrestrial wetlands and their copepod communities in southern Africa

South Africa occupies a vast area stretching from the western Cape Province in the south to Namibia in the west and subtropical Kwa Zulu-Natal on the East Coast. In the north it is bordered by Botswana, Zimbabwe, and Mozambique. Very little is known regarding the freshwater invertebrate fauna of these neighboring countries. There are two landlocked countries within the borders of South Africa, the mountain kingdom of Lesotho, and Swaziland. Except for the eastern border of Lesotho, which it shares with South Africa, nothing is known about the water bodies and freshwater fauna of these two countries. Lesotho has become more accessible with the construction of the very large Katse Dam, which was built as a source of water for South Africa and power for Lesotho. Water is a critical resource in the subcontinent of southern Africa, where rivers flow erratically and natural lakes are few. Most of South Africa lies in the arid latitudes of the southern hemisphere where rainfall is seasonal, the mean annual figure being 475 mm compared with a global average of 860 mm. There is grave concern about the availability of water in the next decades, and it has been predicted that there will be severe water shortages, despite the fact that more than 100 major impoundments have been built in 23 drainage basins (Noble and Hemens 1978). Many of the wetlands have been drained for agriculture and polluted by mining, industry, and informal settlements. There is a diversity of wetlands in southern Africa, such as marshes, vleis, pans, temporary pools, mountain tarns, coastal lakes, and in Namibia, wetlands with some unusual local names such as "oshana" (a shallow watercourse which may become a flat expanse of sand in the dry season) and "ondombe" (a deep, large pool which may retain water year-round) (Clarke and Rayner 1999).

The information on cyclopoids and harpacticoids in southern Africa is limited. There are no records of subterranean species. Most species were described by Brady, Sars, or Kiefer from 1904 to 1934, and no research has been done since then. Three of the better known cyclopoids are *Mesocyclops major, Thermocylops oblongatus,* and *Afrocyclops gibsoni.* These species are usually collected from permanent waters such as man-made impoundments and reservoirs. Except for coastal lakes which are estuarine in origin, South Africa has no natural lakes (Lake Chrissie is a large shallow pan). Species such as *Thermocyclops schuurmanae* and *Microcyclops crassipes* have been recorded from the vleis of the Western Cape.

Information on arid-adapted species of Diaptomidae is available in Rayner and Heeg (1994) and Rayner (1999). Species which are adapted to temporary waters belong to the subfamily Paradiaptominae, and it seems likely that they are obligate temporary

pool dwellers. All these species will have resting eggs and this will be a safeguard against extinction despite environmental pressures. The six calanoid species which occur in the Western Cape Province of South Africa (*Lovenula simplex, Paradiaptomus lamellatus, P. peninsularis, P. hameri, Metadiaptomus capensis, M. purcelli*) are probably the most vulnerable. They are all endemic, occurring in low-lying vleis and temporary pools. This area of the Cape has been isolated by the uplift of the Cape Fold Mountains in the middle Tertiary, and some species occupy a very small geographical area. Any change in sea level would be a threat, especially to *Paradiaptomus peninsularis*, which is confined to the narrow Cape Peninsula. The western and central areas of South Africa are semi-arid, with hundreds of temporary pools and pans. Two species that are very common and widespread in semi-arid areas are *Lovenula falcifera* and *Metadiaptomus meridianus*. They often co-occur and are adapted to wide variations in altitude, water temperature, and salinity. In contrast, *Lovenula excellens* has been recorded only from the Lake Chrissie area of Mpumalanga, where its ancestor (probably *L. falcifera)* appears to have been trapped in an ancient river system. The fourth *Lovenula* species, *L. africana*, has been recorded from waters of high conductivity from Ethiopia through East Africa, with the southernmost record being Makgadikdadi Pan in Botswana. Its affinity for saline waters is confirmed by its presence in this pan, where birds' legs are often encrusted with salt deposits. With the exception of the rare *Paradiaptomus natalensis*, all the other known African species of *Paradiaptomus* (*lamellatus, schultzei, similis, rex, hameri, peninsularis, warreni*) occur in temporary waters. Both *P. schultzei* and *P. similis* extend their range into North Africa, and *P. rex* is known from Senegal, Upper Volta, and Chad. *Metadiaptomus meridianus* and *M. colonialis* occur extensively in permanent waters, although *M. colonialis* is a subtropical species. The other known African species (*chevreuxi, capensis, purcelli, aethiopicus, mauretanicus, gauthieri*) are temporary pool dwellers.

Species of *Tropodiaptomus* and *Thermodiaptomus* of the subfamily Diaptominae are found mainly in permanent, warm waters. *Tropodiaptomus bhangazii* has been recorded from one small lake, Bhangazi South on the KwaZulu-Natal Coast, and is endangered especially from pollution in an area of controversial dune mining for titanium.

From the days of colonization of South Africa in the 17th century, the land and its fauna and flora have been ravaged. There is a great deal of information on the loss and threatened extinction of the vertebrate fauna, but little attention has been paid to the invertebrates and especially freshwater Crustacea. Wetlands have been drained for agriculture, and overgrazing by cattle has caused serious erosion. The African people judge their wealth by head of cattle, and this has serious implications. In the major cities, pollution of rivers and ground water is serious, especially in the mining areas. Informal settlements, which are always established near rivers or streams, are a serious source of pollution, not to mention the health problems of malaria and bilharzia. More than a quarter of the population is poor and illiterate, and there is an ongoing conflict between conservation of resources and impoverished people. The hope lies in the education of the youth, and every effort is being made to encourage them to understand what conservation means. Environmental education has a high priority in schools and universities.

With regard to the freshwater Copepoda, some species are threatened and some may have already become extinct, especially in marshy areas that have been drained. The positive aspect lies in the vastness and semi-aridity of the land, as well as the inaccessibility of some of the mountainous areas. Although water is scarce and rainfall unpredictable in the arid areas, copepod populations have evolved survival techniques. Despite the harsh conditions, it seems doubtful that extinctions will occur in arid-adapted species. Species in the Western Cape that occur in low-lying vleis are probably at risk, and it is possible that some of them have become extinct. As always, there is a great need for more research, but this will not happen until funds are available.

D. Stream degradation and surface wetlands loss in the USA

Aquatic ecosystems in the USA have been strongly affected, in some cases destroyed, by dams or channelization, water-level control, contaminants and reduced water quality, and introductions of exotic species (Mac et al. 1995). Recent data for several major watersheds indicates that only a tiny proportion of each is protected from development, with much original forest cover lost (e.g., Alabama/Tombigbee, 0% protected and 25% forest lost; Mississippi, 2 and 52%; Hudson, 2 and 9%) (Revenga et al. 1998). Only 2% of the 5.1 million kilometers of streams remain free flowing and undeveloped (Abell et al. 2000).

The rapid pace of development in the past century has led to destruction of an unknown number of ephemeral water bodies and to silting of streams. Because of the poor knowledge of most groups of aquatic invertebrates including copepods in North America, it is impossible accurately to assess the main threats to their existence (Strayer 2000). A case in point is an endemic genus of cyclopoids, *Rheocyclops*, several species of which were recently described from streambeds and a cave in the southeastern USA (Reid et al. 1999). Although most of the habitats were considered relatively unaffected by human activities, only 29 specimens of the most numerous species were collected, and of some species only 1 or 2 individuals were found. The extent to which silting or pollution might affect these populations is unknown.

Although calanoid copepods are relatively large and easily collected, and some are brightly colored, the distributions of many, especially those inhabiting small and/or ephemeral waterbodies, are known only fragmentarily. For instance, *Aglaodiaptomus kingsburyae* was described from a roadside ditch in Oklahoma and a small pool and a pond in Texas in 1975, and *A. marshianus* was described in 1953 from Lake Jackson, northern Florida. *Hesperodiaptomus augustaensis* was first found in a temporary pond in Georgia in 1910 and was reported in 1938 from a floodplain pond, which had already been destroyed, in North Carolina. None of these species has been reported since. *Hesperodiaptomus californiensis* was described from three vernal pools in northern California in 1996. *Skistodiaptomus carolinensis* is known only from two large artificial lakes in western North Carolina.

As in most of the rest of the world, thorough local surveys are necessary to underpin estimates of conservation needs of the microcrustacean faunas. Although individual states and private conservation agencies sponsor faunal inventory programs, there is as yet no national survey or central information source for all faunal groups.

E. Conservation concerns regarding Brazilian copepods

Knowledge of the copepod fauna of Brazilian fresh waters is quite disparate if we consider the pelagic and benthic habitats separately. Although Brazil is poor in natural lakes, the number of artificial lakes formed by damming medium and large rivers is large and continues to grow with the construction of new hydroelectric dams in the north and central-west. The zooplankton of these waterbodies has been extensively and intensively studied, and the copepod diversity is well known. It appears that this fauna may be threatened by species recently introduced into reservoirs in the Brazilian southeast, such as the Afro-Asian cyclopoid *Mesocyclops ogunnus* (Reid and Pinto-Coelho 1994). We cannot ignore the possibility that the native species of *Mesocyclops* (*M. brasilianus, M. meridianus*) and perhaps other genera may be supplanted by introduced species.

In addition, the damming of rivers has led to the disappearance of many floodplain lakes, and it is possible that certain copepod species will not survive in the new environmental conditions. The harpacticoid genus *Potamocaris* is widely distributed in the Paraná and Paraguay River basins and in the small rivers of the Brazilian east coast, where its members live in the interstitial water of sandy riverbeds. The damming and growing pollution of the rivers by domestic and industrial wastes, as well as agricultural and mining activities may bring changes in the granulometry and oxygen that threaten the survival of these harpacticoids. For now, data are lacking to evaluate the extinction risk of these species.

Knowledge of the diversity of copepods in benthic and ephemeral habitats is very fragmentary because of the great extent of the country, the enormous diversity of aquatic habitats, the varying methodologies of the few ecological studies (most of which treated the macrofauna), and the lack of a national project of faunistic studies. Existing data are spotty and result from individual initiatives by a small number of investigators. The distribution of most benthic copepod species reflects more the distribution of research institutions where there are or have been researchers interested in the group, than the true distribution of the animals. A pioneering initiative is the BIOTASP Project (Biota of São Paulo), sponsored by FAPESP (Fundação de Amparo à Pesquisa do Estado do São Paulo), which aims mainly to finance projects on the biodiversity of the state of São Paulo. Mosses and other microhabitats of the Atlantic Forest biome are inhabited by cyclopoid species which can be considered in the Red List category of Lower Risk (conservation-dependent). *Muscocyclops operculatus, Bryocyclops caroli, B. campaneri, Hesperocyclops herbsti*, and *Metacyclops oraemaris* are all known only from remnants of the Atlantic Forest, which since 1500

has been gradually and continuously devastated for farming, ranching, and residential purposes. The uppermost layers of the substrate in the restinga (coastal dune forest) of the coastal plain of the state of São Paulo are made up of decomposing fallen leaves, sediment, and plant roots, forming a soft substrate in which *Allocyclops silvaticus* and *Metacyclops hirsutus* live. *Metacyclops paludicola* was described by Herbst (1959) from *Sphagnum* mats in this coastal plain and never found again, in spite of collecting efforts in different seasons about 70 km to the north in the same type of habitat (Rocha, unpublished data). Tiny restinga pools are inhabited by an undescribed, planktonic species of the cyclopoid genus *Neutrocyclops*. All these species of the restinga forest are also conservation-dependent, since the area that they occupy is under intense human pressure for tourism development. Much of the forest has been razed, with no effective measures by governmental authorities to preserve representative areas of this ecosystem.

Semiterrestrial habitats of the cerrado (savanna) of central Brazil, including permanent marshes, wet campo marshes, and ephemerally to permanently moist organic soils, harbor a highly diverse copepod fauna, which is up to now known only through studies in a small area. Of the 79 copepod taxa recorded in such habitats by Reid (1994b), 44 endemic species are threatened by the continual expansion of pasture and farmland, changes in drainage patterns, and input of fertilizers and pesticides. These factors may be highly damaging and cause the elimination of species about which we know nearly nothing regarding their geographical distribution, biology, and ecological preferences.

F. Conservation concerns regarding Mexican copepods

Only three neotropical diaptomid species were included as Threatened in the 1996 Red List, and four species were listed in the DD (Data Deficient) section. Recent surveys have provided new information to propose additional species to be included in the list, and also to exclude at least one. *Microdiaptomus cokeri*, recently redescribed by Elías-Gutiérrez and Suárez-Morales (1998), is the only true troglobitic diaptomid copepod known in the Americas. It is known exclusively from a cave system in northeastern Mexico (Osorio-Tafall 1942, Elías-Gutiérrez and Suárez-Morales 1998), and its local distribution in the cave remains unknown. These caves are increasingly used to provide water for human activities (mainly watering cattle), and the system is connected to the heavily polluted hydrological basin of the Panuco River. Hence, as recommended by Elías-Gutiérrez and Suárez-Morales (1998), this species should be included in the next IUCN list as endangered.

Two species, *Mastigodiaptomus reidae* and *M. maya*, were recently described from a single small ephemeral pond within the limits of a protected area (Calakmul) in southeastem Mexico (Suárez-Morales and Elías-Gutiérrez 2000). However, increasing human pressure is expected over the entire area; the type locality is within an archaeological site that will be progressively developed for tourism. The distribution of this species is still unknown, but it is probable that, as is common in diaptomid copepods, it is restricted in both time and space (Dussart and Defaye 1995), and should be considered vulnerable.

Leptodiaptomus dodsoni was described recently (Elías-Gutiérrez et al. 1999) from a single ephemeral pond near the large Lake Chapala in northwestem Mexico; two individuals were also collected in Lake Chapala. The entire perimeter of this lake is under human pressure due to agricultural development and water extraction; in particular, the type locality has adjacent rural communities that use water from the pond.

Leptodiaptomus mexicanus was described in 1901 from an undetermined locality near Mexico City. It was not observed thereafter, until it was collected recently in a small (less than 1 km^2) temporary pond located between the lanes of a highway. The male was described based on this material (Grimaldo-Ortega et al. 1998). The species appeared in this pond over a period of only one month. Only one Mexican calanoid species has been removed from the 1996 Red List.

Mastigodiaptomus montezumae was included in the DD (Data Deficient) category, but was recorded in several localities in central Mexico (Santos-Silva et al. 1996). Several species of cyclopoid copepods were described recently from isolated populations in sinkholes and associated cave systems in the karst plains of the Yucatan Peninsula. Some occur in only a single system, with apparently very low population numbers. Many sinkholes all over the Yucatan are being used for touristic, recreational, and water supply purposes. The isolated populations of some of these species (*Mesocyclops chaci*, a well and a cave; *M. yutsil*, a

few isolated wells and cenotes; *Diacyclops puuc*, a semi-enclosed cenote; *D. chakan*, several isolated sinkholes; see Fiers et al. 1996, Suárez-Morales et al. 1996, Suárez-Morales and Rivera-Arriaga 2000) seem to indicate that they are vulnerable.

G. Copepods in East Asia

In the 1996 Red List, only one copepod, *Neutrodiaptomus formosus*, was listed from East Asia (Japan). This is not because there are few species to be listed in East Asia, but because there was no person who could cover East Asian copepods among the writers of the 1996 List. It is needless to say that there are as many species described from East Asia, especially from China and Japan, as from Europe and other geographic regions, and that some species in East Asia are recorded from very limited localities (sometimes only from type localities). These could be ranked as "VU D2" because of recent general environmental changes in their habitats due to global warming, acid rain, artificial land improvements, and so on. In the new Red List, we will add such rare Chinese and Japanese copepods as were recorded only from the type localities, mainly according to Shen (1979) and Mizuno and Miura (1984).

II. SUMMARY

The number of copepod species of concern to be entered in the next IUCN Red List will much exceed the 118 species listed in the 1996 version. The number of species considered recently extinct has increased from 2 to 6; more than 220 species are now considered under some degree of threat. The increased number of species resulted directly from information provided by several contributors who did not participate in composing the former version; on the other hand, as several of us have noted, many more species could be added. As expressed in various ways by all the contributors, the basic taxonomy, preferred habitats, and composition of local continental copepod faunas are under active investigation in many parts of the world. There are, however, some rays of hope. For example, Maier (1998) and Maier et al. (1998) called attention to the fact that, while natural temporary ponds in riverine floodplains are disappearing in Germany, temporary ponds that are artificially maintained in early successional stages by vehicular activity, mainly in military reserves, continue to support rare crustaceans, including 4 species of copepods. Reid (1994a) suggested that because many copepod taxa are highly endemic, strategies aimed at conserving many small areas might be appropriate; and the increased concerns of local authorities for conserving green strips, and riparian wetlands, erosion control, and groundwater pollution abatement will go far to preserve suitable habitats for microcrustaceans. Specialists are beginning to include assessments of the conservation status of copepods in their publications (e.g., Elías-Gutiérrez and Suárez-Morales 1998, Boxshall and Jaume 2000, for anchialine caves). In recent decades a heartening degree of attention has been given to preserving special kinds of surface wetlands, and to problems with groundwater pollution in many countries.

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