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Investigations towards the restoration of wetlands in the Tijuana Estuary with special regard to brackish and saline ponds

Untersuchungen zur Renaturierung von Feuchtgebieten im Tijuana Ästuar unter besonderer Berücksichtigung von brackwasserhaltigen und salinen Teichen

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Abstract

This study represents the first comprehensive biological and hydrochemical investigation of small coastal ponds in the saltmarsh dominated Tijuana Estuary, southern California (U.S.). Special attention is given to the brackish water biotopes.

Different salinities and considerable fluctuations in water level characterized these shallow ponds and restrict the biological settlement. Fluctuations of salinities ranged from brackish water to hyperhaline water conditions. Due to different salinity levels, the ponds vary in hydrochemistry, macroinvertebrate species composition and plant communities. The macroinvertebrate community of the brackish waters were dominated by Gastropoda*,* Odonata*, and* Coleoptera *containing a mixture of freshwater/brackish water species and marine macroinvertebrates. Typical plants of the brackish habitat were* Typha domingensis *(Southern cattail), and* Scirpus californicus *(California bulrush) associated with* Juncus acutus *(Siny rush). These brackish habitats with a wide range of salinity fluctuations are sparsely colonized but represent a niche for typical highly adaptable species. Especially, it is a biotope for species with a wide range of salt tolerance. Therefore, endangered species occurred besides introduced or invasive species in the ponds of the Tijuana Estuary. This fact has to be taken into account in case of wetland restoration. Due to the freshwater influence, the restoration of brackish habitats focuses on the problem of invasive species.*

Keywords: *Wetland Restoration, Saltmarsh, Coastal pond, Tijuana Estuary, Invasive species, Macroinvertebrates, Management, Conservation, Brackish water*

Zusammenfassung

Die vorliegende Arbeit befasst sich mit der Situation des Tijuana-River-Ästuars im Südwesten Kaliforniens und untersucht insbesondere Flachgewässer mit Brackwassercharakter. Verschiedene Salzgehalte und erhebliche Schwankungen der Wasserstände sind für diese Gewässer charakteristisch und limitieren die biologische Besiedelung. Die Unterschiede in der Salinität reichen dabei von Brackwasserbedingungen bis hin zur Hypersalinität. Aufgrund der verschiedenen Salzgehalte variieren die Gewässer in der hydrochemischen Zusammensetzung, der Makroinvertebratenzusammensetzung und der Pflanzengesellschaften. Die Gruppe der Makroinvertebraten in den Brackwasserbiotopen wird von Schnecken, Libellen und Käfern dominiert, wobei Süß- und Brackwasserarten zusammen mit marinen Invertebraten auftreten. Typische Pflanzen der Brackwasserlebensräume sind *Typha domingensis* und *Scirpus californicus*, verbunden mit J*uncus acutus*-Pflanzen.

Solche Brackwasserbiotope mit ihren stark schwankenden Salzgehalten sind zwar artenarm, aber sie stellen zugleich Nischen für Organismen mit speziellem hohem Adaptationsvermögen insbesondere hinsichtlich der Salztoleranz dar. So wurden bei den Untersuchungen gefährdete, aber auch invasive Arten gefunden. Diese Besonderheit ist bei allen Sanierungs- und Renaturierungsaktivitäten zu berücksichtigen.

Schlüsselwörter: Feuchtgebiete Renaturierung, Salzmarsch, Küstengewässer, Tijuana Ästuar, invasive Arten, Makroinvertebraten, Naturschutz, Brackwasser

1 Introduction

The importance and ecological functions of coastal saltmarshes range from stabilization of fine sediments, serving as a protective buffer and filter between land and sea, over the blending of terrestrial and marine fauna, to refuge for migratory shorebirds and waders (Laegdsgaard 2006). Nevertheless, these habitats have been destroyed and changed. Coastal saltmarshes in southern California have experienced a loss of approximately 75–90 % of their area compared to pre-settlement values (Powell 2006). The degradation of saltmarshes has different causes. Generally, agricultural practices, changes of hydrology, natural processes (flood, sedimentation), urbanization, habitat fragmentation and the invasion of exotic species lead to disturbances and alteration of estuaries (Laegdsgaard 2006). As a result, morphology and ecology of the area were altered; composition of flora and fauna changed, native species became extinct and numerous species are listed as threatened and endangered. Several processes are non-reversible and the restoration is therefore difficult. Generally, restoration efforts focus on weeds removal, fence off areas for protection and natural regeneration (Laegdsgaard 2006), re-vegetation, and transplantation of saltmarsh plants. Elevation, tide, and salinity play important roles for the success of restoration and establishment of salt marsh areas (Laegdsgaard 2006). Furthermore, restoration projects encompass reinstating of hydrological regimes in connection with excavation of sediments and altering of surface features (O' Brien & Zedler 2006). These alterations, however, lead to artificial conditions (O' Brien & Zedler 2006).

Adaptive management is an important method for coastal ecosystem restoration projects (Thom 2000). The method of adaptive management (experimental tests in a restoration site/ learning by doing, Thom 2000) was and is used for restoration projects in the Tijuana Estuary in California, especially for the actual control and removal of invasive species.

The Tijuana River National Estuarine Research Reserve (Tijuana Estuary) is one of the largest remaining saltmarshes in southern California. It is surrounded by the growing cities of Tijuana, Mexico, Imperial Beach, CA and San Diego, CA. Urbanization and inputs of debris, raw sewage and industrial effluents have led to multiple alterations and a disturbance of this ecosystem. In particular, the rapidly growing city Tijuana, Mexico, with wastewater discharge to the Tijuana River is a major cause of such adverse environmental effects to the estuary. Nevertheless, efforts have been made for restoration and protection of the estuary. The Tijuana Estuary Tidal Restoration Program (TETRP) focuses on the restoration of habitats that have lost area and tidal flushing.

The importance of brackish habitats in the Tijuana Estuary is:

- refuge for animals when the estuary has high tide (Zedler et al. 1992)
- biotope for species which use brackish and salt marsh habitats such as rails (Zedler et al. 1992)

The small brackish and saline coastal ponds in the Tijuana Estuary have not been studied very well so far. Therefore, the aim of this study was to investigate four selected ponds in the Tijuana Estuary and integrate these biotopes into future restoration plans. More specifically, this paper provides an overview of the composition of the macroinvertebrate community, vegetation and hydrochemical conditions of the ponds. Another aim was to find species characteristic for brackish coastal ponds.

The sampling site and sampling points were chosen based on differing varieties of the ponds (vegetation, macroinvertebrates), differing levels of salinity (water body), water depths, availability/accessibility, and missing comprehensive survey of these ponds in the Tijuana Estuary research.

2 Study area

The Tijuana River National Estuarine Research Reserve (TRNERR, Tijuana Estuary) is located in southern San Diego County, California, U.S. (32°35' N, 117°07' W) (Fig. 1), north of the United States – Mexican border at the mouth of the Tijuana River. The marsh-dominated, coastal plain estuary covers approximately 1,024 ha (Zedler et al. 1992). Influenced by marine water from the Pacific Ocean and fresh water from the Tijuana River, the area is a mixture of different habitats, such as dominantly saltmarsh areas, fresh-brackish marsh areas, tidal creeks, open tidal channels and mudflats, sand dunes, beaches, and salt pans. Historically, natural catastrophic events (e. g. 1983 El Niño event, catastrophic flooding) and a variety of human activities (e. g. sewage disposal practices, agricultural uses, military installations, apartment buildings along the beach) shaped the Tijuana Estuary and altered the habitats (Zedler et al. 1992). Presently, the Tijuana Estuary is one of the 27 protected areas of the National Estuarine Research Reserves (NERRs – nationwide network of the U.S.) and was designated a "wetland of international importance" (2005) in the Ramsar list (Ramsar Convention On Wetlands).

The Tijuana region has a mediterranean climate with a mean rainfall of 250 mm per year, which mainly precipitates intermittently between November and April. Long dry summers with little rainfall, and wet winters are characteristically. The mean temperature is 23°C. Mean temperatures range from 7°C in winter to highs of 25°C in summer (O' Brien & Zedler 2006). Extreme conditions in this region are dry years with low rainfall and wet years with winter storms and floods (Zedler et al. 1992). The vegetation in the estuary is influenced by the amount and timing of rainfall and the river discharges into the entire watershed (443,323 ha watershed of the Tijuana River) (Zedler et al. 1992). High evaporation and hot dry desert winds are also important factors for the flora and fauna (Zedler et al. 1992).

Flowrate of the Tijuana River shows considerable fluctuation during most years. The estuary is dominated seasonally by marine hydrology. Occasionally, the area is more strongly influenced by fresh water during flood events (California Department of Parks and Recreation, U.S. Fish and Wildlife Service, National Oceanic and Atmospheric Administration 2000, Zedler et al. 1992).

The form of the Tijuana valley at the mouth is flat and wide. The predominant geologic formations are quaternary and recent alluvial and slope wash deposits above sandstones, shale and limestones (California Department of Parks and Recreation, U.S. Fish and Wildlife Service, National Oceanic and Atmospheric Administration 2000). These unconsolidated deposits are comprised of clay, silt, sand and cobble-sized particles.

The estuary's north arm in the upper area of the salt marsh was chosen for the present investigation. Biological and hydro-chemical samples were collected from four small, shallow coastal ponds nearby the military landing field (Fig. 1 and 2).

The establishment and development of the coastal ponds is unknown. The military landing field was built in 1953, and a brackish marsh appeared at the terminus of the urban drai-

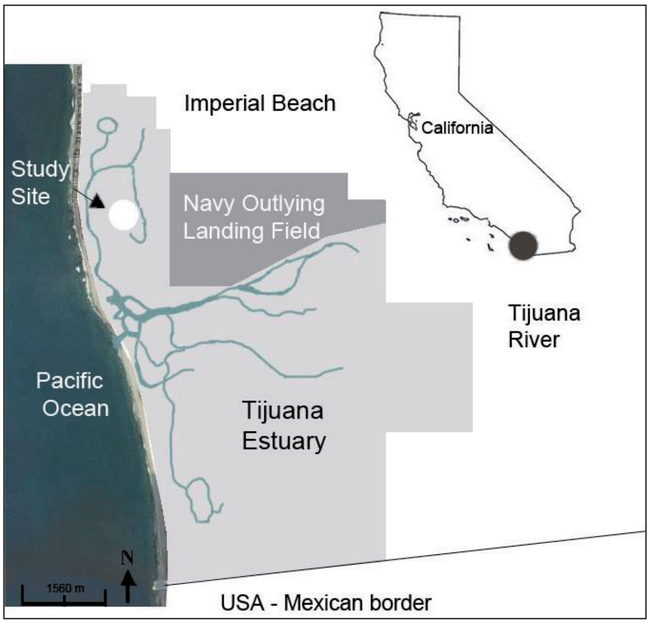

Fig. 1: Location of the Tijuana Estuary in California.

Abb. 1: *Lage des Tijuana Ästuars in Kalifornien.*

nage from this field (Zedler et al. 1992). The sampling sites were located in this area. A photograph of the Tijuana Estuary from 1978 shows gravel excavations which perhaps led to the development of the ponds. These ponds are influenced by the freshwater inflow from the Navy Landing Field especially during the rainy season and they are without opening to the ocean and without surface outflow. Minerals and salts are therefore concentrated in these water bodies. As a result of these environmental conditions, the salinity of the investigated ponds fluctuated from brackish to hyperhaline salinity level (Tab. 2). Pond three was isolated from pond four during the samplings in October, 2006. Nevertheless, pond three and four are connected at higher sea level. The surface soil of the sampling site was covered with a salt crust.

The Comprehensive Management Plan for Tijuana River National Estuarine Research Reserve and Tijuana Slough National Wildlife Refuge (California Department of Parks and Recreation, U.S. Fish and Wildlife Service, National Oceanic and Atmospheric Administration 2000) encompasses the following goals for habitat restoration and protection:

I. Goals for the NERR System (California Department of Parks and Recreation, U.S. Fish and Wildlife Service, National Oceanic and Atmospheric Administration 2000):

- "*Ensure a stable environment for research through long-term protection of National Estuarine Research Reserve resources;*
- *Address coastal management issues identified as significant through coordinated estuarine research within the NERR System;*
- *Enhance public awareness and understanding of estuarine areas and provide suitable opportunities for public education and interpretation;*
- *Promote federal, state, public, and private use of one or more Reserves within the NERR System when such entities conduct estuarine research; and*
- *Conduct and coordinate estuarine research within the NERR System, gathering and making available information necessary for improved understanding and management of estuarine areas*."

II. Goals of the FWS for the National Wildlife Refuge System (California Department of Parks and Recreation, U.S. Fish and Wildlife Service, National Oceanic and Atmospheric Administration 2000):

- "*To preserve, restore, and enhance in their natural ecosystems (when practicable) all species of animals and plants that are endangered or threatened with becoming endangered;*
- *To preserve a natural diversity and abundance of fauna and flora on Refuge lands; …*"

The Tijuana Estuary lost 80 % of its daily tidal prism between 1852 and 1986 as a result of different events (Zedler et al. 1992). Therefore, actual goals for restoring the estuary would aim to both increase the tidal prism and at the same time, combat sedimentation (California Department of Parks and Recreation, U.S. Fish and Wildlife Service, National Oceanic and Atmospheric Administration 2000).

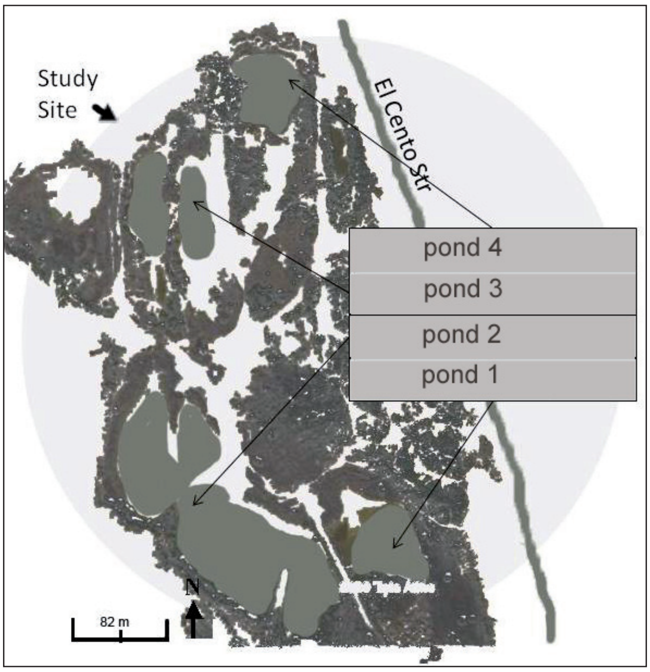

Fig. 2: Map of the study site in the Tijuana Estuary.

Abb. 2: *Lageplan des Untersuchungsgebietes im Tijuana Ästuar.*

3 Methods

In October 2006, one-time samples were collected from the four coastal brackish and saline ponds in the high salt marsh area of the Tijuana Estuary after a dry summer period, when water depth in the ponds ranged between 0.10 m and 0.20 m.

3.1 Biological analyses

Macroinvertebrates were sampled from pond 1, 2, 3 and 4 at several locations of each pond (Fig. 1, 2). A qualitative, multihabitat sampling approach was conducted to characterize the macroinvertebrate communities in the different ponds. A hand net with mesh size 3 mm (diameter [Ø] = 200 mm) was used to collect macroinvertebrates from the aquatic macrophytes, the water column and the bottom substrates (approximately 10 cm depth). Macroinvertebrates were collected at each pond over a period of 4 hours. The abundances of different organisms were estimated based on a seven degree scale (n = number of individuals; **1:** $n = 1$; **2:** $2 < n \leq 20$; **3:** $21 < n \leq 40$; **4:** $41 < n \leq 80$; **5:** $81 < n \leq 160$; **6:** $161 < n \leq 320$; **7:** $320 < n$ (Alf et al. 1992)). The organisms were then preserved in ethanol (70 %) for further taxonomic analysis in the laboratory. All macroinvertebrates were identified to the lowest taxonomical level, in some cases to family or genus level and usually species level (Abbott 1974, Borror & White 1970, Burch & Tottenham 1980, Emerson & Jacobson 1976, Hogue 1974, Jensen 1995, Keen & Coan 1974, Milne & Milne 1980, Merritt & Cummins 1996, Morris 1958, Morris et al. 1980, Powell & Hogue 1979, Rehder 1981, Smith & Carlton 1975, Usinger 1956, and White 1983). Identification of dragonfly larvae was improved by identifying adult insects in the field (Manolis 2003).

Parallel to the sampling of macroinvertebrates, plants were mapped in the same locations of each pond in a 10 meter radius around the ponds according to the Braun-Blanquet method (Braun-Blanquet 1932). Species were identified in that area using Lightner (2006). For all ponds, total percent cover of each plant species was estimated and was judged on a 100 % cover value. Information about plant spreading, degree of endangerment, invasive species and other data were provided by several databases (Global Invasive Species Database 2009, California Invasive Plant Council 2009, Calflora 2009, California Native plant society 2009, USDA PLANTS Database 2009).

3.2 Hydrochemical analyses

Hydrochemical sampling was performed also once at the same time as the biological collection procedure. The standardized hydrochemical methods for analyses are shown below (Tab. 1). Temperature, dissolved oxygen, and pH were measured with a portable hydrolab meter in the field. Samples were filtered (filter size: 0.45 µm) for photometric analyses.

Additionally, salinities were measured bimonthly from September 2008 to April 2009.

4 Results

4.1 Water condition

Ponds 1 and 2 were predominately euhaline/ polyhaline brackish waters while ponds 3 and 4 were characterized by hyperhaline salinity levels. Investigations of the salinity in the ponds of the Tijuana Estuary (Fig. 3) showed a high fluctuation of salinity, particularly in ponds 3 and 4. These considerable fluctuations of salinity ranged from 30 ppt (December 2008) up to 152 ppt (October 2008) in pond 3. Salinity ranged from polyhaline brackish (pond 1) to hyperhaline level (pond 3, 4) in October 2006.

The results of all measurements and hydrochemical analyses are shown in Table 2.

The oxygen contents from pond 1 to pond 4 decreased while salinity increased. The temperature of the ponds ranged from 20.9 to 22.5°C. This temperature in connection with the high organic matter concentration leads to low oxygen levels in the ponds. The electrical conductivity was very high in ponds 3 and 4 reflecting the high salinities. The content of organic matter was relatively high in all ponds (Tab. 2). However, only moderate concentrations of nitrate and ammonia were found.

4.2 Macroinvertebrate communities and vegetation

The macroinvertebrate community of the investigated ponds was characterized by low species diversity (Tab. 3). A total of 24 taxa (16 families) was recorded at all sampling sites. The total number of species at each site ranged from 18 in pond 1 to only 4 in pond 3. Six groups of invertebrates (*Crustacea*, *Gastropoda*, *Heteroptera*, *Odonata*, *Coleoptera* and *Diptera*) were identified, which mainly occurred in pond 1. *Gastropoda*, *Odonata* and *Coleoptera* were most species rich, with four or five species, while other groups contained only one or two different species.

Some dragonflies were sighted but only in flight in the surroundings of ponds 1 and 2, e. g. *Anax junius* mainly occurred in the cattail stands. The survey of all dragonflies of pond 1 and 2 was not possible and has to be completed with further macroinvertebrate collections in spring.

Tryonia imitator, *Anax junius* and *Trichocorixa reticulata* were the most dominant species at sampling sites. Furthermore, *Trichocorixa reticulata* occurred in all ponds with high abundance, especially in pond 4.

Tropisternus salsamentus, *Berosus* sp., *Enochrus* sp., and *Hygrotus* sp. were coleopterans which were collected exclusively in the brackish pond 1 with a salinity of 25.4 ppt. *Ochthebius rectus* and *Ochthebius lineatus* occurred in salinities of 110 ppt (pond 4) and, therefore, seem to prefer higher salinities.

A limited number of different functional feeding groups were found at the sampling site. Overall, the aquatic functional feeding groups with the highest number of species and density were predators and grazers. A high number of grazers resulted from a higher proportion of snails in the macroinvertebrate community at the sampling time. The high number of predators in pond 1 is due to the different dragonfly species and beetle larvae.

Tab. 1: Methods used for hydrochemical analysis.

Tab. 1: *Verwendete Methoden für die hydrochemischen Analysen.*

Parameter	Method
Phosphorus (Orthophosphate) 1)	ascorbic acid method, APHA Standard methods, range: 0–2 mg/L
Total Phosphorus 2)	DIN EN ISO 6878: 2004, range: 0.03–4.6 mg/L PO_4
Nitrate 1)	cadmium reduction method, APHA Standard methods, range: 0–30 mg/L
Ammonia 1)	phenol-hypochlorite method according to Strickland & Parsons (1972), range: 0.1–10 µg-at/L
Biochemical Oxygen Demand (BOD) 1)	5-day incubation, APHA Standard methods
Chemical Oxygen Demand (COD) 2)	DIN 38 409 (H44), range: 5–60 mg/L O_2
Chloride 2)	titration according to Mohr, DIN 38 405 (D1-1)
Salinity	YSI 85 for pond 1 and 2, refractometer (range of 0–160 ppt) for pond 3 and 4

1) Laboratory of the Graduate School of Public Health at the San Diego State University, USA

2) Laboratory of the University of Applied Sciences Magdeburg-Stendal, Germany (Samples were frozen during the transport to Germany.)

Tab. 2: Results of hydrochemical and -physical investigations.

Tab. 2: *Ergebnisse der hydrochemischen und -physikalischen Untersuchungen.*

date of sampling:	**10-12-2006**			
parameter	**pond 1**	**pond 2**	**pond 3**	**pond 4**
salinity (ppt)	25.4	34.2	66.4	110.0
oxygen (mg/L)	6.96	5.39	4.29	/
temperature (ºC)	20.9	21.4	22.0	22.5
pH - value	8.8	8.4	8.3	8.0
orthophosphate (mg/L)	0.467	0.342	0.306	0.646
nitrate (mg/L)	< 0	0.263	0.185	1.123
ammonia (mg/L)	0.210	0.263	0.212	0.024
date of sampling:	**10-19-2006**			
BOD (mg/L)	23.18	10.65	20.92	27.28
COD (mg/L)	228.5	290.0	291.5	420.5
total phosphate (mg/L)	0.481	0.468	0.900	0.941
chloride (g/L)	15.9	19.8	43.9	58.5
electrical conductivity (µS/cm)	3090	3990	7470	9470

Due to the similar bottom substrate and morphological structure of the ponds only a few types of habitats were found. Pelal (e. g. mud), psammal (e. g. sand), and phytal (e. g. plants) are the common habitat preferences of the macroinvertebrates sampled during this study.

Vegetation

In general, the area was abundantly covered with vegetation. The diversity of plants around the investigated ponds at the sampling sites of the Tijuana Estuary is low to moderate. The plant diversity around pond 1 is higher than the diversity near the other ponds. *Juncus acutus* spp. *leopoldii* (leopold's rush), *Salicornia virginica* (pickleweed), *Distichlis spicata* (saltgrass), and *Jaumea carnosa* (salty susan) are dominant elements of the plant community and occurred in the surrounding of all ponds usually in high abundances. The area around the edge of pond 2 was relatively sparsely covered with vegetation due to a salt crust on the soil.

The plant community of pond 1 was dominated by *Salicornia virginica* (pickleweed), *Typha domingensis* (southern cattail), *Distichlis spicata* (saltgrass), and *Scirpus californicus* (California bulrush).

Typha domingensis and *Scirpus californicus* are common in the surrounding of the ponds and indicate freshwater influences. Therefore, the plant community of the ponds is made up of typical saltmarsh plants (high marsh) and plants of the riparian habitat of the Tijuana Estuary.

Cordylanthus maritimus spp. *maritimus* (Saltmarsh bird's-beak) grew in the high marsh of the Tijuana Estuary. This endangered plant was found in the surroundings of pond 3 and 4. The plant is endangered in California and elsewhere (California Native Plant Society, http://www.cnps.org/; 03.04.2009).

The Leopold's rush is included in CNPS's inventory of rare and endangered plants on list 4.2 (limited distribution) (http://www.calflora.org, 20.08.2009).

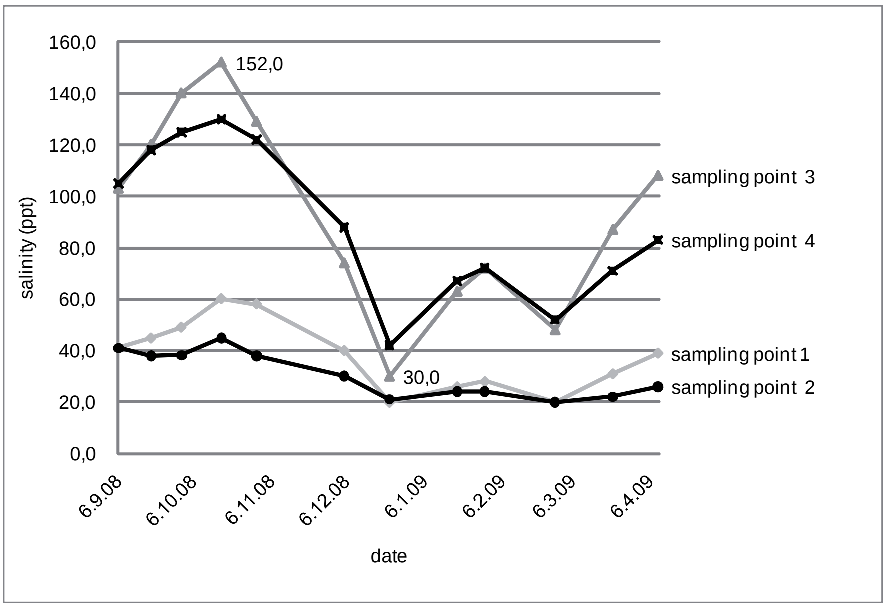

Fig. 3: Time variation curve of salinity in the investigated ponds.

Abb. 3: *Ganglinie des Salzgehaltes in den untersuchten Teichen.*

Tab. 3: Abundances of macroinvertebrate species in the ponds.

Tab. 3: *Abundanzen der Makroinvertebraten in den Teichen.*

Species name	Occurrence	pond 1	pond 2	pond 3	pond 4
Crustacea					
Isopoda	among the *Typha*	3			
Ostracoda	no direct sampling	4	3		
Palaemon macrodactylus	detritus among the *Typha*	4			
Gastropoda					
Acteocina sp.	fine sand, sandy mud, sand		3		
Barleeia californica	mud, sandy mud	3	4		2
Cerithidea californica	mud		4	3	3
Melampus olivaceus	mud	2	4		
Tryonia imitator	sandy mud, fine sand, mud	5	5	4	
Heteroptera					
Trichocorixa reticulata	among the *Typha*, mud, other	4	4	4	6
Odonata					
Anax junius (adult)	in flight, in *Typha* population	5	3		
Enallagma sp. cf. (adult)	in flight and sitting of pickle-weed	2			
Ischnura sp. (larvae)	among the *Typha*	4			
Sympetrum corruptum (adult)	in flight and sitting of pickle-weed or saltgrass	3	2		
Coleoptera					
Berosus sp. (larvae)	mud/roots	2			2
Enochrus cf. sp. (adult)	substrate among the *Typha*	1			
Hydrophilidae sp. (adult)	substrate among the *Typha*	1			
Hygrotus sp. (adult)	substrate among the *Typha*	2			
Ochthebius sp.(adult)	mud/roots -riparian		3		2
Ochthebius rectus (adult)	mud/roots-riparian				1
Ochthebius lineatus (adult)	mud/roots-riparian				1
Tropisternus salsamentus (adult)	substrate among the *Typha*	2			
Tropisternus sp. (adult)	substrate among the *Typha*	1			
Diptera					
Chironomidae	mud	2			
Ephydridae sp. (pupae)	mud/roots			3	

Foeniculum vulgare (Sweet fennel) was introduced in California from Europe and Mediterranean area. It is not native in California. *Foeniculum vulgare* is listed in the 2006 list of the California Invasive Plant Council (Cal-IPC). The invasive impact of this plant is statewide high (http://www.calflora.org, 12.04.2009). This plant is common at the brackish pond 1.

5 Discussion and conclusions

The investigated coastal ponds in the Tijuana Estuary probably arose from gravel mining. Due to freshwater impacts on the ponds and resulting brackish water conditions, the ponds play a large role for the habitat diversity in this marsh region. Moreover, the man-made ponds are important habitats for threatened or endangered species. The ecological functions and the importance of brackish habitats in the Tijuana Estuary are:

- increase of habitat diversity in the estuary
- habitat for typical brackish water species
- refuge for endangered species (endangered salt marsh bird's beak)

The hydrological conditions influence the hydrochemistry in these shallow ponds and can vary dramatically during a year. Important factors are dilution due to rainfall and runoff in wet season, and concentration of salts in the dry season in connection with evaporation. Therefore, it is important to note that the salinity reflects only the hydrological condition. Long-term investigations are necessary to better characterize the water chemistry and biology of the ponds.

The nature and variation of salinity is an important ecological factor and influences the species composition of water organisms and the communities of plants in the ponds.

Tab. 4: Vegetation (cover abundances according to Braun-Blanquet) at the ponds.

Tab. 4: *Vegetation (Deckungsgrade nach Braun-Blanquet) an den Teichen.*

Species name	Common name	pond 1	pond 2	pond 3	pond 4
Juncus acutus ssp. *leopoldii*	Leopold's rush	1	2a	2a	2a
Salicornia virginica	Pickleweed, Virginia glasswort	3	3	2b	2b
Distichlis spicata	Saltgrass	2b	3	2b	2b
Typha domingensis	Southern cattail	2b			
Scirpus californicus	California bulrush	2a	2b		
Jaumea carnosa	Salty susan, Marsh jaumea	1	+	2b	2a
Cuscuta californica; Cuscuta salina var. major	Chaparral dodder; Goldenthread	+		2a	
Limonium californicum	California sea lavender, marsh rosemary	+	+	2a	2a
Foeniculum vulgare	Sweet fennel	+			
Eriogonum fasciculatum	California buckwheat, Eastern Mojave buckwheat	2a		2a	2b
Cordylanthus maritimus spp. *maritimus*	Saltmarsh bird's-beak			R	+
Isocoma menziesii	Menzies' goldenbush	1		2a	2a
Monanthochloe littoralis	shoregrass	2a			

The species composition of pond 1 differed from the other ponds. Besides the *Gastropoda*, *Odonata* and *Coleoptera* were the most conspicuous elements of the invertebrate community. Characteristic brackish macroinvertebrates in the region are *Tryonia imitator* (brackish water snail), *Ostracoda*, *Anax junius* (Green darner), *Tropisternus salsamentus*. *Tryonia imitator*, a small brackish water snail, occurs in shallow, submerged waters and tolerates a wide variety of salinities (Kellog 1980). The snail is threatened and listed in the global and state ranking list of conservation (http://www.dfg.ca.gov/biogeodata/cnddb/pdfs/spanimals.pdf, 20.08.2009).

Berosus sp., *Enochrus* sp., *Hygrotus* sp., and *Ochthebius* sp. are important coleopterans of brackish and saline water conditions in the Tijuana Estuary.

The adverse environmental conditions and high salinity level led to a decrease in species richness and lack of fauna, e. g. absence of dragonflies in pond 3 and 4.

Species which preferred the phytal were dominant among *Odonata* and *Coleoptera*. The aquatic plants and the root system of riverine vegetation are biotopes for these organisms, and the occurrence of these habitats is an important factor influencing the occurrence of these macroinvertebrates.

Most species of pond 1 were found in the water body and bottom substrate (a mixture of mud, sandy mud and detritus) of the *Typha domingensis* population. Therefore, the aquatic plant community plays a role in the diversity and composition of macroinvertebrates in the ponds.

Restoration projects start with the establishment of goals. Measures of the success of restoration projects depend on the attainment of the aims.

The following first goals for the protection and restoration of the investigated ponds (based on this investigation) with special regard to the goals of the management plan of the Tijuana Estuary are:

- Protect the brackish water habitat as an important habitat of the Tijuana Estuary for the preservation and restoration of native habitat diversity.
- Increase diversity and populations of endangered plants such as salt marsh bird's beak, typical brackish water species, and shorebirds at the sampling site of the investigated ponds.
- Integrate the brackish ponds in the development of an adaptive invasive species management plan.
- Integrate these research findings and adaptive management into restoration efforts.
- Integrate pond 1 and pond 4 in biological monitoring programs.

The restoration of brackish habitats focuses on the adverse impact of invasive species. The Tijuana Estuary has experienced an invasion of non-native plants. These plants are widespread in the area. Common outcomes are displacement of native plant species and to changes in the food web. The management of invasive plant species of the Tijuana Estuary will be developed and broadened.

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