# Factors Contributing to the Distribution of the ETS *Sousa chinensis* Population Suggest an Ecosystem Approach for Restoration[1]

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**Abstract:** The Eastern Taiwan Strait (ETS) population of *Sousa chinensis* is listed as critically endangered by the International Union for Conservation of Nature and numerous anthropogenic impacts continue to threaten its survival. Planning for population conservation and restoration or preparing effective environmental assessments for future coastal development requires an understanding of the factors that determine why *Sousa chinensis* occupies its preferred habitat. To help predict important habitats for *S. chinensis*, potential factors that influence the distribution and abundance of the ETS population were briefly reviewed using available distribution data, environmental information, and literature on the behavior-ecology of this species. Preliminary findings suggest the distribution of the ETS population of *S. chinensis* may be related to the distinctive habitat found along the central west coast of Taiwan: a shallow gently sloping bottom adjacent to broad intertidal foreshore mudflats enriched by river discharges. Although apparently restricted to shallow waters <30m, key factors that make this habitat suitable for *S. chinensis* are likely the high primary and secondary productivity that support its prey fish production. Since prey availability is an important limiting factor controlling the distribution and abundance of the ETS population, an ecosystem approach for preserving and restoring components of the coastal habitat that ultimately support the food web for prey fish is recommended.

Keywords: Indo-Pacific humpback dolphin, Eastern Taiwan Strait Population. *Sousa chinensis,* Coastal habitat restoration, ecosystem approach

## 1.0 Current Geographic Range of ETS Population of *Sousa chinensis*

The ETS population occupies a relatively narrow corridor along Taiwan's central west coast, a shallow area with moderate gradients, broad intertidal mud flats, and a 2 to ≤4m tidal range. This depositional zone exists due to the gradual slope, abundant sources of riverine sediment, and oceanographic conditions that allow accumulation. The west coast is unique compared to other coastal regions of Taiwan as it is one of the few areas in Taiwan with a shallow bottom extending some distance from shore (Shao et al. 1993). West coast rivers fed by abundant rainfall are the source of sediment. The range of the ETS population tracks closely with the coastal zone adjacent to greatest annual rainfall

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[1] The third in a series of reports on the *Sousa chinensis* ETS population

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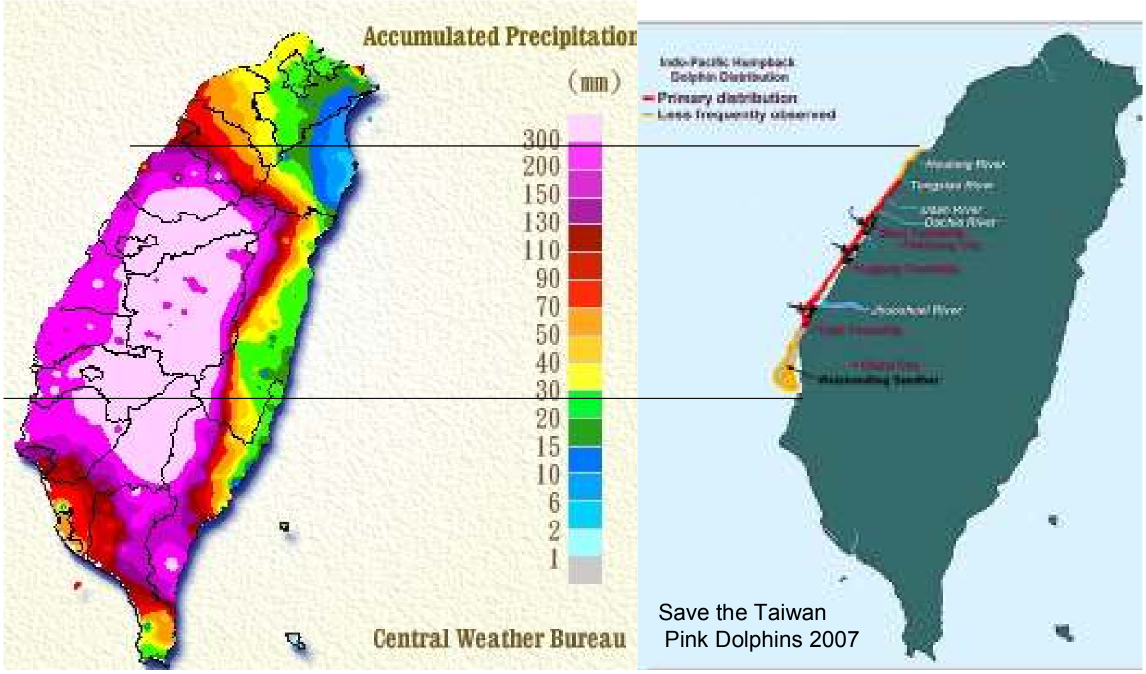
(Figure 1.1). The resulting annual riverine water and sediment discharges are substantial, but these have been reduced over the past decades by barriers and diversions for industrial, municipal or agricultural use. Reductions in source sediment, land reclamation for development, and shoreline armoring have altered coastal processes and habitats.

Comparing the ETS population range with coastal bathymetry confirms that it is generally restricted to the broad shallow (<30m) mud/sand bottom areas from about 23° 30´N to 24° 45´ N. This shallow corridor is wider north and south of the Choshui River (shoreward of the Changyun Ridge). Most confirmed observations were less than 4 km from shore. A very basic figure showing the extent of mud flats along this coast is generally a good match to the *S. chinensis* N-S range (Figure 1.2). The intertidal flats sand/mud bottom was evident in more detailed 1950 charts from the US Army Corps of Engineers (NF 50-4 and NG 51-13; Series L594) as well as in current nautical charts. However, there have been significant coastal changes since 1950. The most obvious is the loss of intertidal mudflat area due to coastal land reclamation and the movement and shrinkage of the Waisanding sand bar. Based on past river diversions, the Waisanding bar now depends on Choshui River sediment that has been reduced and then diverted by breakwaters from the Formosa Petrochemical Corporation facility (Chen 2006). Although coastal land reclamation is undertaken to promote industrial growth, the economic valuation used to justify this development generally ignores the natural resources and the ecosystem goods and services they provide, which are permanently lost when these habitats are reclaimed (Wang et al. 2010).

## 2.0 Factors Influencing the Relative Abundance of *S. chinensis*

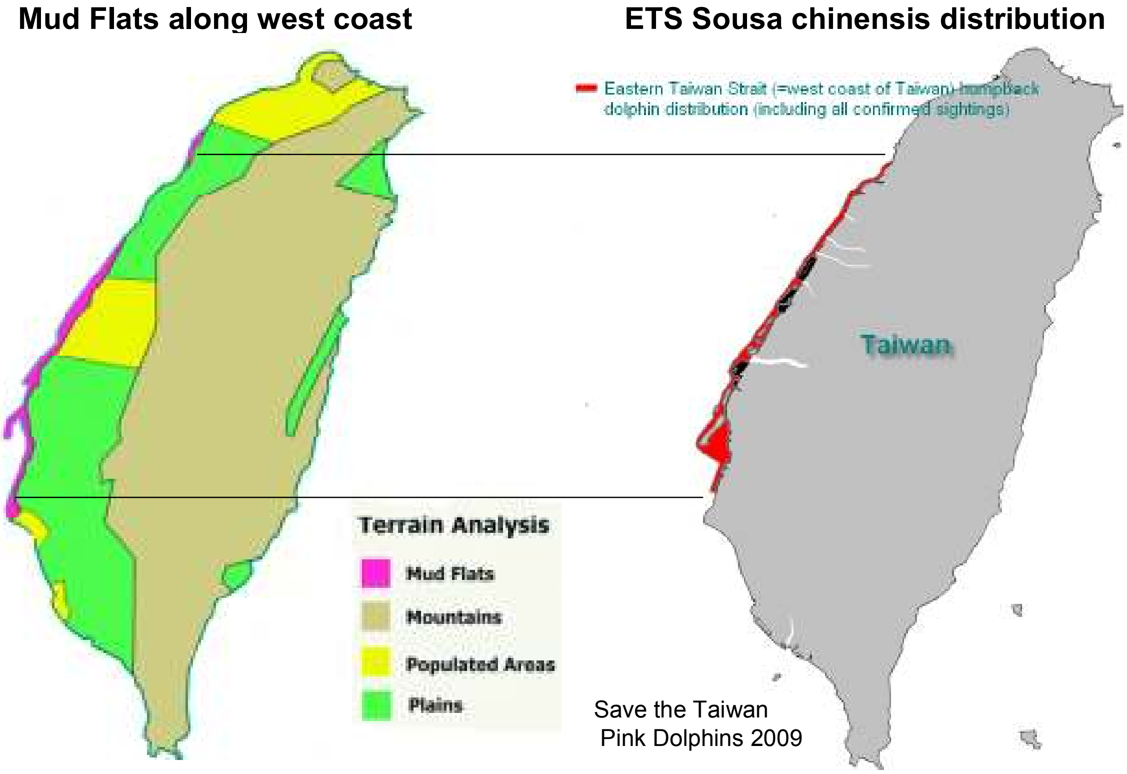
Surveys by Chou et al. (2009) and Wang et al. (2007) indicate that the distribution of observed dolphins in the ETS population is not uniform throughout its range and they are more frequently observed near river mouths, man-made harbors, and the Waisanding sand bar. The two general areas along the west coast with more frequent sightings (red areas on the right side of Figures 2.1 and 2.2, Chou et al. 2009) are characterized by high riverine discharge levels, natural sand bar formation, or habitat complexity resulting from anthropogenic alterations. River mouths with dredged channels and sandbars provide topographic relief. Harbors with breakwaters act in much the same manner as constructed reefs to enhance habitat for prey fish. These changes in topography and rugosity create more bottom relief and surface area, alter circulation, and provide additional food and shelter, which attracts fish species that are probable prey for *S. chinensis*.

The western coast of Taiwan is part of the continental shelf of the East China Sea and is enriched by river discharges that make it a highly productive fishing ground (Hung, 1991). Comparing *S. chinensis* distributions with data on river inputs suggests that areas with the higher abundance are adjacent to rivers with the highest water discharge (Taichi, Wu and Choshui rivers: Figure 2.1) and/or the highest river sediment discharges: (Taan, Wu and Choshui rivers: Figure 2.2). Table 2.1 provides estimates of the annual discharges from rivers in the ETS population range except on Phengu (Kao 2005, Hsu



Save the Taiwan Pink Dolphins 2007

Figure 1.1. Accumulated precipitation compared to range of ETS population. The N-S range of the ETS population is along coastal zone with highest precipitation.



**Mud Flats along west coast**

**ETS Sousa chinensis distribution**

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Figure 1.2. Comparison of west coast mud flats with ETS population range. Distinctive mud flats extend 3-8 km seaward. Low tide exposes at least several km of mud in most areas

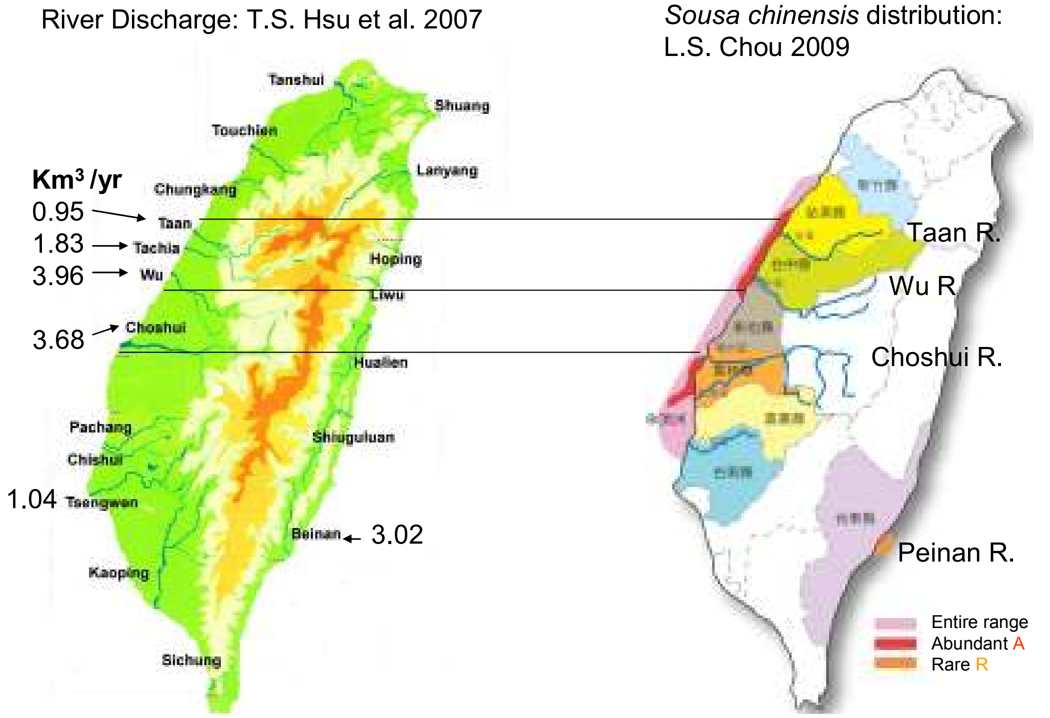

Figure 2.1. River discharge compared to areas where *S. chinensis* is relatively more abundant. Within its range, relative abundance is greater near rivers with high discharge.

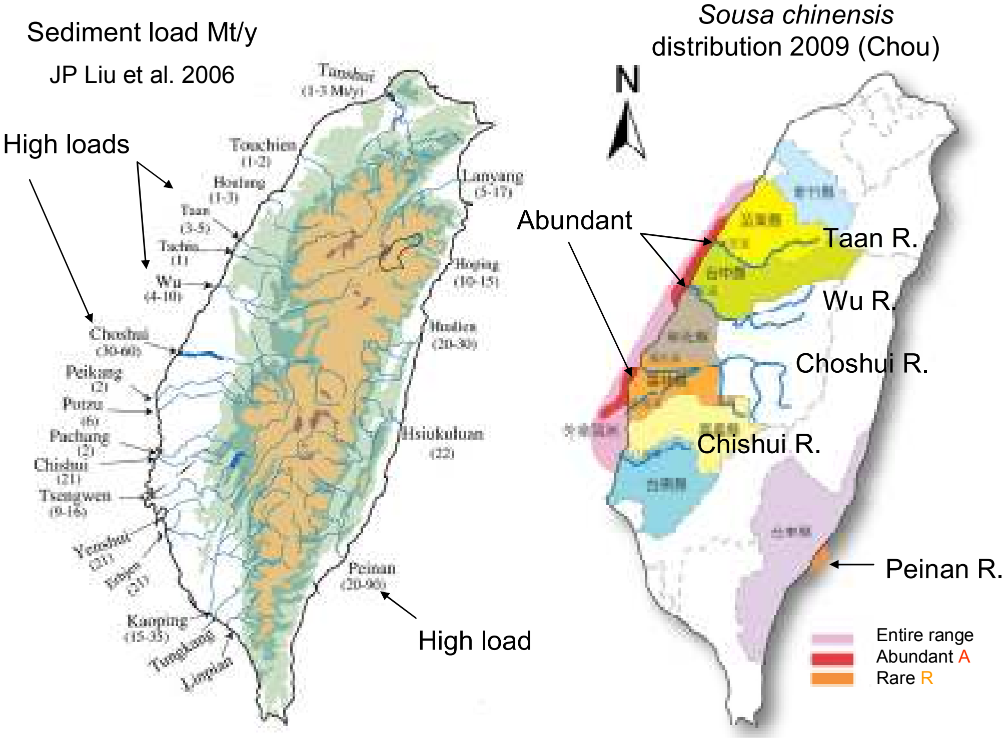

Figure 2.2. River sediment discharge compared to areas where *S. chinensis* is relatively more abundant. Within its general range, relative abundance is greater near rivers with high sediment discharge. Long-term littoral net sediment transport is to the south.

2007 and Liu 2006). Discharge rates vary significantly over time, but provide a general comparison among the major rivers within the ETS population range. More recent water diversions for industrial use, such as the Taan River usage for the Central Taiwan Science Park, have significantly reduced the discharge of several rivers. These water diversions reduce sediment, much of which fine-grained particles that are important carriers for organics and particle reactive elements (Kao et al. 2008). Interestingly, the only dolphins. reported along the east coast were off the Peinan River, the river with the highest sediment discharge on the East coast

The ETS population range appears restricted to shallow sand/mud bottom adjacent to broad intertidal mud flats, but relative abundance may be related to river discharge levels. However, these physical factors alone do not fully explain the ETS population range or distribution. A review of literature on the behavior-ecology of *S. chinensis* throughout its range indicates that there is no clear preference for sand/mud bottom habitat per se, although the distribution is generally limited to areas less than 20 m deep. Studies in Australia or South Africa indicate that habitat preferences exhibited by other *S. chinensis* populations are quite diverse and include a wide variety of shallow near-shore habitats including natural or constructed reefs, bays, and mangroves/estuaries, rocky coastal areas. Where observed farther from shore and away from riverine influence, *S. chinensis* is often associated with protected areas, such as inshore of the Great Barrier Reef. Thus, *S. chinensis* does not appear directly dependent of sand/mud substrate for reproduction, feeding, or growth to maturity. As a top mammalian predator with high energy requirements, it seems more likely that *S. chinensis* habitat preferences may be directly related to the availability of key prey. Although habitat preference has a genetic component, it can be modified by learning, and this may certainly be the case in highly intelligent and adaptive dolphins.

**Table 2.1**

**Major River Parameters and *S. chinensis* Relative Abundance (A)**

| River (new WRA spelling) | | Ave. Water Discharge $Km^3$/yr | Ave. Sediment Discharge Mt/yr | Drainage Sq. Km | Length Km |
|---|---|---|---|---|---|
| Houlong (Hou-Long) | | 0.63 | 1-3 | 472 | 58 |
| Taan (Da-An) | A | 0.95 | **3-5** | 758 | 96 |
| Tachia (Da-Jia) | A | **1.83** | 1 | 1,236 | 124 |
| Dadu or Tatu (Wu) | A | **3.96** | **4-10** | 2,026 | 119 |
| Choshui (Jhuo-Shuei) | A | **3.68** | **30-60** | 3.157 | 187 |
| Peikeng (Bei-Gang) | | 0.76 | 2 | 597 | 82 |
| Putzu | | ? | 6 | 426 | 75 |
| Pachang (Ba-Jhang) | | 0.64 | 2 | 441 | 81 |
| Peinen R (Bei-Nan) | R | 3.02 | 20-60 | 1,603 | 84 |

## 3.0 Availability of Prey as a Key Driver of *S. chinensis* Distribution

A number of factors influence the distribution and abundance of marine mammals, but prey abundance is the factor most often cited regardless of the spatial and temporal scale of the study (Perrin et al. 2009). Hastie et al. (2004), in examining functional mechanisms underlying cetacean distribution patterns, noted that hotspots for bottlenose dolphins are related to foraging. Such a positive relationship between *S. chinensis* abundance and prey availability has been described by several researchers (Hung 2004, Law 2001, Parra 2006, and Reyes 1991). Hung (2004) observed that *S. chinensis* movement is influenced by prey availability in China and Parra (2006) indicated that habitat preferences and movement patterns in Australia are influenced by their prey. These studies suggest that the availability of energy rich and abundant prey fish that compose the primary diet of the ETS population may account, in part, for its distribution and relative abundance along the central west coast of Taiwan.

Prey fish abundance is affected by oceanographic conditions including bathymetry, temperature, and food availability as well as anthropogenic impacts. It is primarily dependent on the quality of their essential habitat[3] and the level of fishing pressure. The rivers provide both the sediment to form the sand/mud habitat and the nutrients that stimulate primary production in pelagic phytoplankton and the microphytobenthic community on the intertidal mudflats. Hung (1975) noted that the central west coast had the highest values for daily primary production in the waters surrounding Taiwan. This primary production along with riverine dissolved organic matter and detritus supports a rich invertebrate community on the mudflats and nearshore zone. This productive community provides food for many of the probable prey fish species, suggesting that the ETS population may depend on a food web based on nutrient enrichment originating from west coast rivers.

Figure 3.1 compares Chlorophyll *a* concentration (an indicator of primary production) during August 1998 (Tang et al. 2002) and the ETS distribution. Relatively high chlorophyll *a* concentrations are associated with the ETS N-S distribution. Using integrated genetic and semi-analytic algorithms, Liu et al. (2007) described water constituents from remote sensing of ocean color and results suggested a similar general pattern with respect to Non Algal Particles (NAP Figure 3.2) and Colored Dissolved Organic Matter (CDOM Figure 3.3). Liu (2007) demonstrated that the different characteristics of Chl-*a*, CDOM and NAP make ideal tracers for observing large-scale river dispersal patterns. The general distribution on these parameters influences the food web that supports the ETS population.

Broad shallow coastal areas may limit the ETS population N-S range by depth, but prey production, stimulated by nutrient enhancement, may determine the abundance or occupation time within the ETS range. The high primary production within the intertidal mudflats and estuaries supports secondary production of invertebrate food for probably prey fish. For example, the density of many invertebrates, such as the horseshoe crab,

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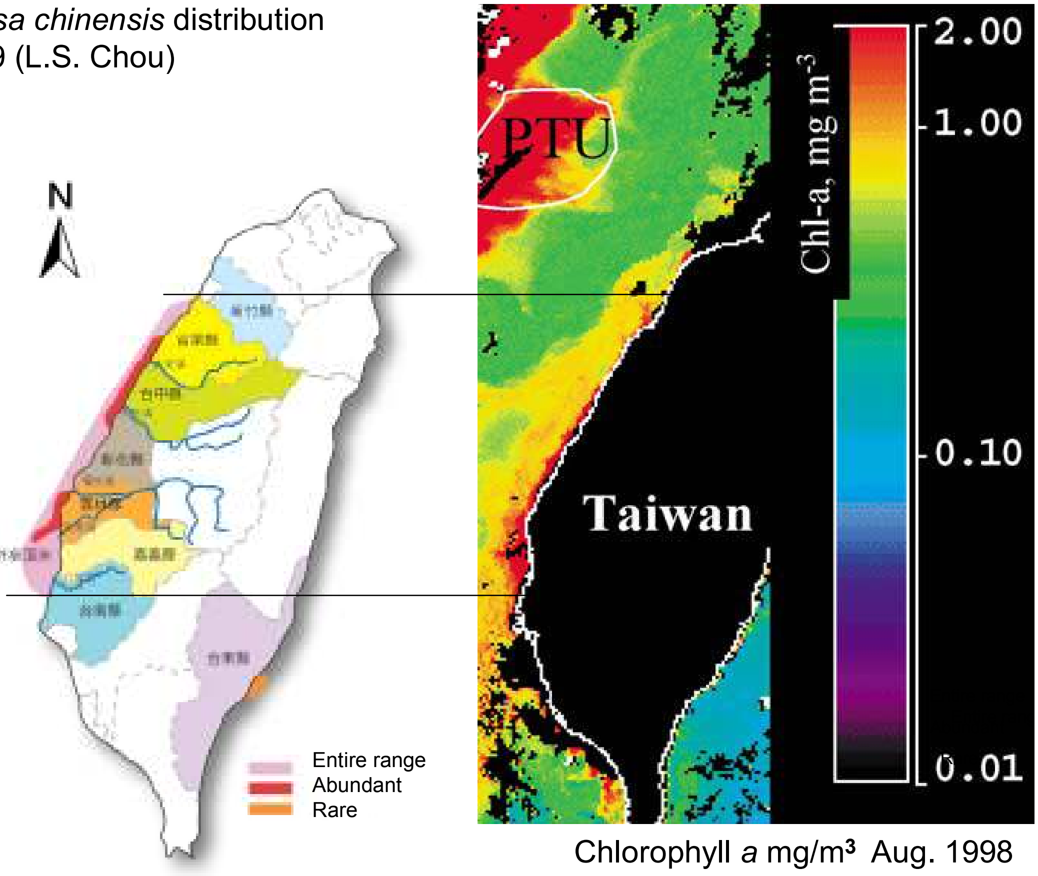
[3] Defined as "those waters and substrate necessary to fish for spawning, breeding, feeding, or growth to maturity." The Sustainable Fisheries Act (US Public Law 104-297)

increases based on the chlorophyll *a* content of the sediment (Hsieh and Chen 2009). Phytoplankton production may be limited in depth due to turbidity, but primary production also includes microphytobenthos[4] on the broad intertidal mudflats. Although microphytobenthic primary production on the mudflats is high, biomass levels appear low due to the effects of invertebrate grazing and resuspension (sensu Blanchard et al. 2010).

D.L. Tang et al. 2002

*Sousa chinensis* distribution 2009 (L.S. Chou)



Chlorophyll *a* mg/m$^3$ Aug. 1998

Figure 3.1. Range of ETS population compared to a sample of chlorophyll *a* density, a measure of primary production. Relatively high productivity is suggested within *S. chinensis* range.

Since most of the probable prey fish species confirmed in the diet of *S. chinensis* from other regions (Sheehy 2009a) have a fairly shallow depth range and feed upon benthic invertebrates, prey availability is also restricted by habitat. Where the shallow coastal corridor to 30m is too narrow or obstructed, there may not be sufficient food available or accessible to support *S. chinensis* and this may partly explain why they are not found in other shallow, but narrower, nutrient rich areas, along Taiwan's southwest coast. Land reclamation and channel creation has already significantly reduced the productive mudflats along the west coast and this may account, in part, for the ETS population decline. About 20% of the earlier expanse of intertidal mudflats and shallow productive

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[4] "Microphytobenthos refers to microscopic, photosynthetic eukaryotic algae and cyanobacteria. Intertidal microphytobenthos include motile benthic diatoms (mainly pinnate) that migrate vertically.

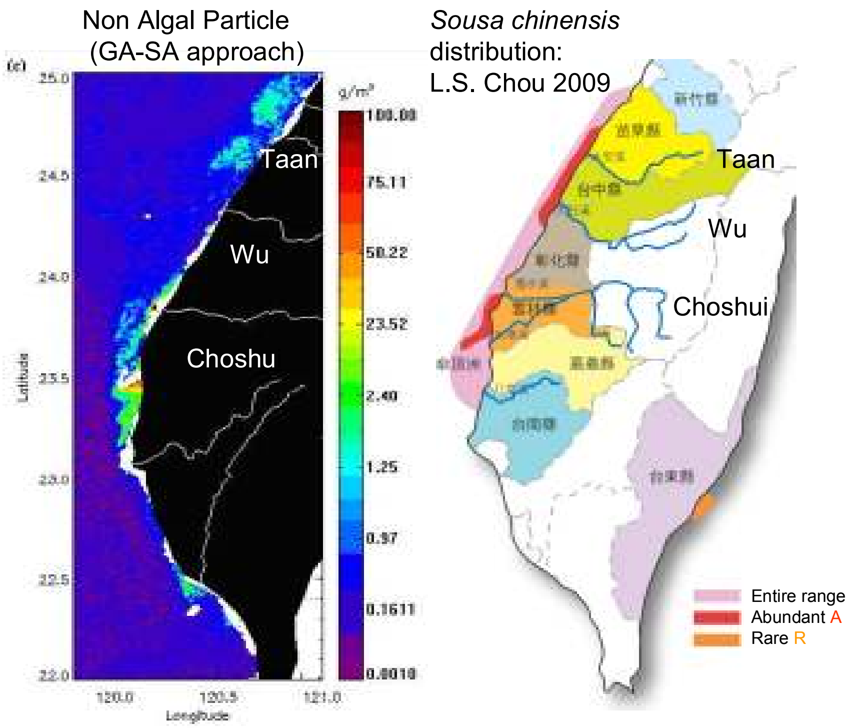

Figure 3.2. Example distribution of Non-Algal Particle/detritus/mineral (NAP) (Liu et al 2007).

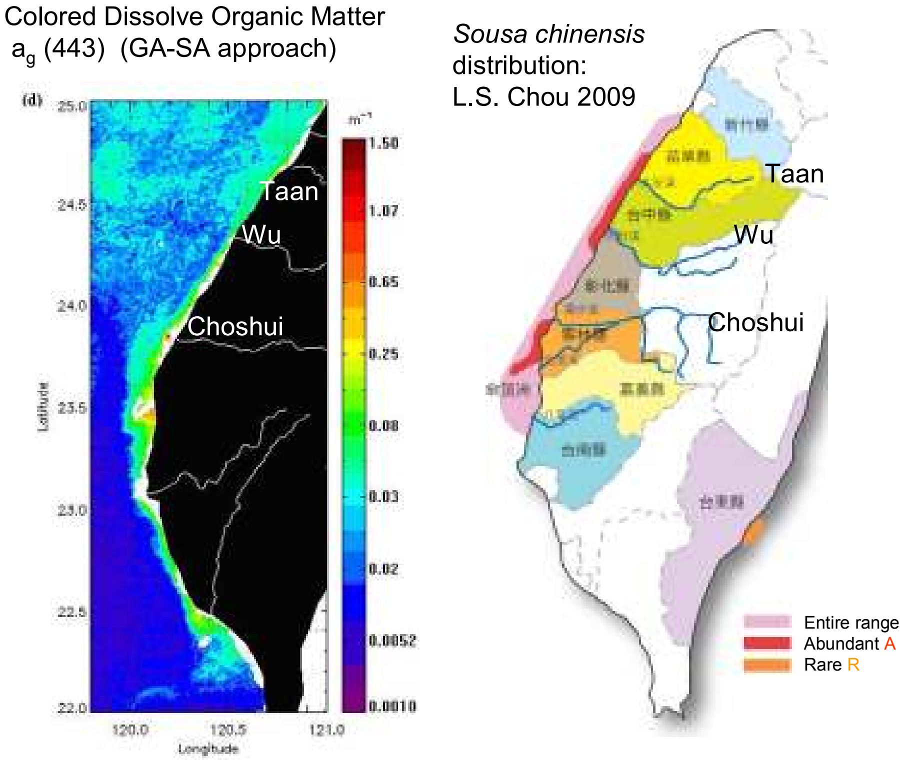

Figure 3.3. Example distribution of Colored Dissolved Organic Matter (CDOM), the optically measurable component of the dissolved organic matter in water (Liu et al. 2007)

areas along the west coast has apparently already been reclaimed and additional reclamation is planned. Estimating lost prey production based on simple consideration of area losses may significantly underestimate the loss as productivity varies considerably and is dependent on which areas were eliminated (McLusky et al. 2006). In this case, a number of land reclamation projects are close to rivers and the loss of productivity may be greater than that reflected by simple calculation based solely on area lost.

## 4.0 Probable Prey Species and Factors Affecting Their Habitat

*S. chinensis* is primarily an opportunistic generalist piscivore and probable prey fish for the ETS population are listed in Table 3.1 (adapted from Sheehy 2009a). Additional fish in the genera *Johnius, Apongon, Sillago, Pomadasys,* and *Liza*, which are listed in the TrawlBase of Taiwan (Shao 2009), as well as *Mugil* and *Coilia,* which are listed as diet items in other populations of *S. chinensis* (Sheehy 2009a), may also be probable prey species. Trawl surveys by Chen (2009) indicated that probable prey and their food items were more common at the most shallow 5m trawl sites. However, since these trawl surveys were all at depths ≥5 m, species found in shallower waters may be under represented or omitted. Of the identified probable prey fish, half are pelagic-neritic and half are demersal or bentho-pelagic. All of the pelagic fish form schools and most of the demersal fish form shoals or spawning aggregations. Such aggregations provide dense prey targets for *S. chinensis*. Two thirds of the listed probable prey fish consume benthic invertebrates and over two thirds consume zooplankton. Only two species have fish in their diets and only three are noted to consume detritus. Their estimated trophic levels (FishBase) range from 2.41 to 4.45. Almost two thirds also have some level of estuarine association ranging from dependence to frequent use. Almost half are found only within the depth range of *S. chinensis* and all but three are found primarily in water less than 50 m. In general, probable prey fish can be characterized as shallow water species, dependent on nearshore invertebrate production for their diet, and exhibiting some form of aggregation.

Available prey density, caloric value, and size will determine whether or not dolphins can acquire enough food to meet their high energetic requirements. Probable prey fish abundance depends on food resources in nearshore waters including the intertidal mudflats, estuaries, and lagoons. Recent studies along the west coast confirm that intertidal mudflats provide important nursery functions for juvenile fishes (Tse et al. 2008). Nearshore mud/sand bottom habitats along the west coast support an abundant benthic crustacean community including Penaeidae and Portunidae (Chou et al. 1999) that are common in the diets of many probably prey fish. Given that nutrient enrichment (including silica - important for diatoms) is highest off those estuaries with the greatest discharge; the resulting primary production and detritus stimulates high benthic and/or planktonic invertebrate production. This production likely influences prey fish abundance through the food web and may ultimately affect the ETS population distribution and abundance.

## Table 3.1

## Characteristics[5] of Some Probable Prey Species [6] of the *Sousa chinensis* ETS Population

| Species | Environment | School /shoal | Estuary use or dependency | Depth Range (m) | Soniferous | Primary diet items | Trophic Level SE | Use |
|---|---|---|---|---|---|---|---|---|
| *Ilisha melastoma* | P-N; A | school | coastal waters, enters estuaries | 5-20 | swimming sound | zooplankton, small benthic crustaceans & mollusks | 3.45<br>s.e. 0.47 | MC |
| *Ilisha elongata* | P-N | school | inshore, enters estuaries, lagoons | 5-20 | swimming sound | benthic crustaceans. zooplankton, fish | 3.79<br>s.e.0.61 | HC |
| *Thryssa spp.* | P-N | school | most inshore: some enters estuaries | <50 | | benthic invertebrates; planktonic crustaceans, | 2.82-3.45 | MC; BA |
| *Thryssa kammalensis* | P-N; O | school | brackish; inshore marine | 1-20 | | planktonic crustaceans, detritus, benthic invertebrates | 3.08<br>s.e.0.36 | SF |
| *Encrasicholina heteroloba* | P; RA; O | school | inshore, estuaries, deep bays | 20-50 | | planktonic crustaceans, zooplankton, fish | 3.27<br>s.e. 0.37 | MC; BA |
| *Nematalosa come* | P-N | school | estuaries, lagoons, brackish seas, | 10-13 | yes (air bubble though anal pore) | phytoplankton; planktonic and benthic invertebrates, detritus | 2.76<br>s.e.0.28 | MC; SF |
| *Spratelloides gracilis* | P-N | inshore school | marine, coastal, lagoon, seaward reefs | 10-50 | yes, pre-spawning? | planktonic invertebrates | 3.04<br>s.e 0.16 | MC; BA |

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[5] Primary references: FishBase, 2009. Froese, R. and D. Pauly. Editors. World Wide Web electronic publication. www.fishbase.org, version (11/2009). and Shao. K.T. The Fish Datebase of Taiwan. WWW Web electronic publication. version 2009/1 http://fishdb.sinica.edu.tw, (2010-2-19)

[6] Initial species list adapted from M.H. Chen (National Sun Yat-sen University) 2009

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| *Pennahia macrocephalus* | D | shoals, | marine, coastal, bays, coral reefs | 3-100 | yes (SBR) | benthic invertebrates and fishes | 4.08 s.e.0.64 | HC |
| *Pennahia pawak* | BP | shoals | marine, coastal, bays | 3-50 | yes (SBR) | benthic and pelagic crustaceans | 3.3 s.e.0.41 | CO |
| *Chrysochir aureus* | BP | shoals, | shallow coastal, bays, brackish | 1-20 | yes (SBR) | benthic crustaceans | 3.5 s.e.0.50 | MC |
| *Johnius amblycephalus* | D | shoals | shallow coastal waters, estuaries, & coral reefs | 3-40 | yes (SBR) | benthic invertebrates | 3.3 s.e 0.40 | MC |
| *Arius maculatus* | D | occasional schools | inshore waters, lagoons, and estuaries | 10-100 | yes, spines-squeaking | benthic invertebrates and small fish | 3.36 s.e 0.46 | CO |
| *Valamugil cunnesius* | D; C | aggregate during sea spawning | estuaries and backwaters, young frequently enter freshwater | 0-40 | yes | detritus, plants, phyto- and zooplankton, organic matter in sand and mud | 2.41 s.e 0.21 | CO; BA |
| *Trichiurus lepturus* | BP; A | juveniles and small adults school | muddy bottom, often enter estuaries | 0-400 | | juveniles- euphausiids, crustaceans, fish. adults- fish; squids & crustaceans | 4.45 s.e.0.77 | HC; GF |

**Environment**: P- Pelagic; D- Demersal; BP- Benthopelagic; N- Neritic; RA- Reef Associated; A- Amphidromous; O- Oceanodromous; C- Catadromous

**Soniferous**: SBR- Swim Bladder Resonation. SPT - Stridulation Pharyngeal Teeth; Swimming sound is also called hydrodynamic noise from densely schooling fish, but it's unclear whether or not this is audible to dolphins

**Utilization**: HC-Highly Commercial; CO-commercial; MC-Minor Commercial; GF-Game Fish; CU- Cultured; SF- Subsistence Fishery; BA- Bait; AQ- Aquarium

Probable prey fish are vulnerable to overfishing, habitat degradation, and pollution. Fishing pressure high enough to significantly reduce the abundance of key prey fish will also affect *S. chinensis* distribution and abundance. Prior to extensive overfishing and coastal development, the productive waters of western Taiwan were the most important inshore fishery zone in Taiwan (Shao et al. 1993). Bottom trawling, in particular, has also done extensive damage to soft bottom habitats and associated benthic communities (Shao 2009). A number of the pelagic species (Engraulidae, Pristigasteridae, and Clupeidea) form dense schools making them relatively easy to harvest in large numbers. All but one of the probable bentho-pelagic and demersal prey fish are soniferous. Soniferous sciaenids are particularly vulnerable when in spawning aggregations and fishers use the sounds they produce to located and harvest them (Mok et. al. 2009). *Valamugil cunnesius* also aggregates during spawning. Fisheries reductions in prey availability can adversely affect dolphin foraging efficiency by increasing foraging energy requirements and thus ultimately adversely impact the ETS population.

The west coast of Taiwan has also been extensively developed with numerous land reclamation and aquacultural activities that have degraded nearshore habitats. Intertidal mudflat loss has been significant along the west coast. The currently proposed Koukuang Petrochemical Technology facility proposed for construction on reclaimed land just north of the mouth of the Choshui River (Figure 5.1) is a recent example of this continuing development effort. In additional to habitat losses, such coastal and riverine industrial development also alters coastal dynamics, increases the probability accidental pollutant spills, and introduces contaminants.

Contamination also causes adverse consequences because even abundant prey, if seriously contaminated, can adversely impact the ETS population. Rivers in Taiwan remain highly polluted and do not have strong self-cleaning and assimilative capacities. Many prey species also have some level of estuarine dependence and may, as a result of greater exposure, have higher contaminant body burdens. Serious pollution along the west coast of Taiwan has been well documented for a number of contaminants and will continue to grow as additional industrial and science parks are constructed on the coast or along rivers discharging into prey fish habitats. Of special concern for the ETS population are those toxic compounds that are: 1) persistent and bioaccumulate reaching high levels in apex predators, 2) endocrine disruptors that interfere with reproduction, and 3) fat soluble contaminants that are concentrated and then transferred from mothers to nursing calves. Given the restricted coastal range of the ETS population and industrial and agricultural development in the region, food web contamination is likely. Although more difficult to detect, sub-lethal and/or cumulative toxic effects can significantly adversely impact small populations.

## 5.0 Suggested Future Actions and Studies

A number of proposed conservation and enhancement measures intended to help preserve the ETS population were identified in earlier reviews (Wang et al. 2007), but they can’t all be implemented simultaneously even if adequate funding was available. Given the cumulative risks and small size of the ETS population, time is of the essence for establishing a priority for proposed actions and an efficient method is needed. These decisions should be based on expected return-on-investment, which in this case is the reduction in risk of ETS population extirpation. A group decision analysis approach (Sheehy et al, 2000, Sheehy and Vik 2002) using an interdisciplinary team of marine mammal, fish and wetland ecologists, coastal zone planners, and restoration specialists is suggested. This approach was recommended by the U.S. National Academy of Science (1992) as an effective means of evaluating complex aquatic restoration projects, has been applied to a range of major coastal and riverine mitigation and restoration applications (Sheehy and Vik 1997). Group decision analysis using can help establish a sound priority for establishing and enforcing MPAs, suggesting habitat enhancement for key prey fish species, and identifying critical riverine and estuarine habitat for preservation and restoration. This type of analysis requires clear objectives, based on expected return-on-investment in terms of the sustainability of the ETS population, and the use of specific evaluation criteria that can be effectively measured when performance is assessed. It may be particularly useful for establishing MPAs, where a range of biological, economic, and social factors measured in different or incommensurate units must be considered.

The proposed Koukuang petrochemical plant site is just North of the mouth of the Choshui River, which has a sediment yield that is among the highest in the world.

Reclaimed land, typical of development along this coastline, can be seen both North and South of the proposed facility.

The Formosa Petrochemical facility, shown on the south, has already altered sediment movement and may be impacting the shrinking Waisanding sand bar, a productive area often occupied by *S. chinensis*

Figure 5.1. Proposed site for a new petrochemical facility in core ETS population habitat. FORMOSAT image 2008 by Cheng-Chien Liu, National Cheng-Kung University, and An-Ming Wu, National Space Organization, Taiwan

Additional studies are needed to further describe the ETS population, but they should not delay urgent and important conservation actions. Given the small population size and cumulative and continuing anthropogenic impacts, prompt protective actions are required. Some investigations are currently underway (Chou, L-S, personal communication), but a few additional studies employing technology that can be implemented fairly rapidly may help. The overall objective of these studies is to provide key data for implementing and ecosystem-based management approach to preserve the ETS population. These investigations are focused on understanding and protecting the prey fish that are critical to preserving the ETS population. Specific recommendations involve delineating important primary and secondary production areas, describing probable prey species distribution and essential habitats, evaluating *S. chinensis* activity or behavior, and testing prototype prey fish enhancement technology.

Satellite remote sensing can provide synoptic and near real-time observations related to primary productivity and other parameters of interest (Liu et al 2007) in different areas within the ETS range. Spectral analysis of available satellite imagery can provide some indication on the spatial and temporal changes in key parameters that may be related to the food web supporting *S. chinensis* and help identify important prey fish production areas for protection and restoration. Changes in probable prey availability may suggest the advantages of establishing temporary protected areas for prey fish and dolphins during critical periods.

Remote sensing data on primary production can also be used to focus benthic surveys. Since most of the probable prey fish feed on benthic invertebrates, a rapid assessment approach in a subset of areas with high primary production might provide further support for the linkage between primary and secondary production at these sites suggesting their relative value. The sediment profile imaging system (Rhoads and Germano 1982) provides a means to conduct a rapid screening assessment of benthic conditions within and surrounding the proposed MPAs and help identify productive areas in need of protection. This is an optical technique that can quickly measure and analyze a number of biological, physical, and chemical parameters relative to benthic production over large areas of ocean bottom. Recent modifications enable it to be used on intertidal mudflats[7]. This survey approach can provide a rapid and cost-effective method to initially relate benthic productivity to essential habitat for key prey fish species, thereby helping to screen areas for future detailed studies, immediate protection, or future restroation (Sheehy 2009b).

Acoustic methods can provide a more rapid non-destructive means of assessing the abundance and distribution of probable prey fish as well as dolphin presence and feeding activity. Both active and passive methods have been suggested for evaluating impacts, understanding dolphin behavior, and quantifying the distribution of probable prey (Sheehy 2009b). Passive acoustic methods can be used to help identify spawning areas for soniferous sciaenids since sound frequency increases during spawning aggregations. Sciaenids are known to feed on benthic invertebrates on sand ridges and aggregate for reproduction often near river mouths and channels. Protection of spawning aggregations

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[7] Personal communications J. Germano and M. Solan

using temporary closures during the spawning season for sciaenids, as suggested by Tu (2001) and Mok (2009), is also recommended. Passive acoustic methods can also be used to monitor *S. chinensis* presence and activity in critical areas.

Active acoustic surveying methods may allow a quicker assessment of pelagic as well as some demersal prey fish. Active acoustic methods can help delineate critical areas for enforced habitat protection and assess performance of prototype enhancement technology (Sheehy 2009b). These methods have been suggested as effective non-destructive approach for sampling pelagic fish in marine sanctuaries (Kracker 2007).

Prey abundance or concentration can be influenced by natural or anthropogenic factors. Enhancing prey availability may aid in conservation and restoration efforts for the ETS population. *S. chinensis* has the ability to take advantage of high density and/or high energy food resources within its normal depth range. *S. chinensis* is commonly observed following trawlers to feed on bycatch discards (anthropogenically concentrated food) in Hong Kong and Australia and apparently use constructed (artificial) reefs in South Africa (Karczmarski 2000). Testing options for prey fish enhancement using constructed reefs or fish attraction devices (FADs) may provide opportunities for prey species enhancement or for temporarily relocating prey and dolphins to avoid construction or dredging impacts or highly contaminated areas. It is essential, however, that fish habitat enhancement methods be applied with caution and used only in conjunction with enforced fishing restrictions and close monitoring to assure that they do not result in unanticipated adverse impacts.

## 6.0 Conclusions

A combination of physical and biological factors define the distribution of the ETS population. The distribution appears related to the distinctive habitat found along the central west coast of Taiwan: a shallow gently sloping bottom adjacent to broad intertidal foreshore mudflats enriched by river discharges. In addition to water depth, key biological factors that make this habitat suitable for *S. chinensis* are the high primary and secondary productivity that support its prey fish production. Indicators of productivity, including Chlorophyll *a*, CDOM, and NAP, are all relatively high along the coastal range of the ETS population. Within this relatively narrow coastal corridor, dolphins are observed in higher frequency near those rivers with the greatest water or sediment discharge, where prey production or availability may be highest.

The structure and function of coastal ecosystems involve complex interactions of variables and it is difficult to prove causality once you get several steps away from the root cause. However, this limited review suggests that prey availability, linked to productive foreshore mudflats and estuaries together with the presence of man-made structures may help explain the distribution of the ETS population. The loss and degradation of some of this productive habitat may account, in part, for the decline of the ETS population. More comprehensive habitat modeling, along the lines suggested by

Redfern et al. (2006), will be needed to predict *S. chinensis* distributions and clarify the ecological processes that determine them.

Since prey availability is likely an important limiting factor controlling the distribution and abundance of the ETS population, effective conservation and restoration efforts must include the components of the coastal ecosystem that ultimately support the food web for prey fish production. Probable prey fish include a range of near-shore demersal, bentho-pelagic and pelagic species, most of which aggregate in schools or shoals and feed primarily on benthic or pelagic invertebrates. Given the cumulative anthropogenic stresses on the essential habitat of probable prey fish, it is critical to implement measures to protect these habitats. Further studies will help to determine the habitats and processes most important for probable prey species and may help identify essential fish habitat vital to sustaining the ETS population.

Because the viability the ETS population depends on the ecology of habitats that extend beyond those directly occupied by *S. chinensis,* an ecosystem-based management approach[8] is recommended to develop an effective program to preserve this population. Adequately addressing the root cause of risks threatening the ETS population must go beyond delineating MPAs based only on predicted dolphin occurrence or considering each threat in isolation. An integrated watershed approach directed at preventing further habitat degradation, reducing contamination, restoring essential prey fish habitats, controlling fishing, and enforcing effective MPAs is critical to the future of the ETS population. A west coast conservation greenway concept, such as that suggested by Hsieh et al (2004), would aid significantly in protecting prey essential fish habitat. The value of this approach is that it reflects strategic, rather than tactical, planning and is focused on understanding *S. chinensis's* life history and habitat requirements to preserve and restore critical ecosystem functions (sensu Hsieh and Chen 2009).

**A** network of enforced MPAs has been suggested as part of a program to conserve the ETS population. Such a network, if developed based on ecosystem functions, diversity, and integrity, may be an important part of an initial response. MPA locations, perhaps augmented with constructed fish habitat enhancements (Sheehy and Vik 1992), might be most useful within and offshore of a select number of estuaries where prey production is high. Since prey abundance may be both spatially and temporally variable, a flexible approach to MPAs including temporary or seasonal restrictions may be appropriate (Hoyt 2005). Although a network of MPAs selected specifically for *S. chinensis* habitat may be required, it is vital to augment such networks with additional conservation and restoration efforts in areas outside the dolphin reserves since other areas, including tidal flats, wetlands, estuaries, and rivers, are closely linked to prey fish productivity. Protecting areas with abundant *S. chinensis* or foraging areas with abundant mature prey fish may be necessary, but is not suffice to protect the ETS population. A holistic ecosystem management approach, which is adaptive and considers habitats that support prey production, is needed for sustaining the ETS population of *S. chinensis.* Such an

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[8] Defined as the management of ocean and coastal resources in a way that reflects the relationships among all ecosystem components, including human and non-human species and the environments in which they live. (US Commission on Ocean Policy, 2004)

approach will promote more sustainable development and provide substantial collateral benefits to many other species.

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