SPECIES COMPOSITION, ABUNDANCE AND DISTRIBUTION OF JELLYFISH IN THE COASTAL WATERS OF PENANG NATIONAL PARK AND MANJUNG

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SPECIES COMPOSITION, ABUNDANCE AND DISTRIBUTION OF JELLYFISH IN THE COASTAL WATERS OF PENANG NATIONAL PARK AND MANJUNG

By

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TABURAN, KELIMPAHAN DAN KOMPOSISI SPESIES OBOR-OBOR DI PERAIRAN TAMAN NEGARA PULAU PINANG DAN MANJUNG

ABSTRAK

Satu kajian mengenai komposisi spesies, kelimpahan dan taburan obor-obor telah dijalankan di perairan Selat Melaka sepanjang 14 bulan sekitar Taman Negara Pulau Pinang (TNPP) (November, 2009 sehingga December, 2010) dan Manjung, Perak (September, 2009 sehingga October, 2010). Kaedah tunda dan kaut telah digunakan untuk mengutip sampel menggunakan bot nelayan dengan kelajuannya kira-kira 2.5 knots nautika semasa air pasang anak. Kaedah kaut menggunakan pemerhatian visual untuk mengesan sampel di permukaan air. Manakala, kaedah tunda memerlukan sebuah pukat tunda yang direka khas untuk menunda di belakang bot nelayan bagi memerangkap sampel obor-obor yang tenggelam. Sejumlah 5 spesies obor-obor dari 5 genera telah dikenalpasti, iaitu *Phyllorhiza punctata*, *Chrysaora* sp., *Rhopilema* sp., *Chiropsoides buitendijki*, dan *Carybdea morbakka*. *Chrysaora* sp. adalah spesies dominan yang menyumbang kepada 95.42% (TNPP) dan 97.66 % (Manjung) dari jumlah obor-obor yang ditangkap. Bilangan maksima obor-obor yang direkodkan adalah 57.07±12.37 individuals/1000m^3 pada bulan Mei, 2010 (TNPP) dan 475.70±183.97 individuals/1000m^3 pada bulan Oktober, 2010 (Manjung). Musim ledakan obor-obor yang ketara berlaku pada bulan September, 2009 dan Oktober, 2010 di Manjung. Di TNPP, tiada ledakan obor-obor yang direkodkan tetapi kehadirannya boleh didapati sepanjang tempoh persempelan. Faktor fiziko-kimia air yang direkodkan di TNPP dan Manjung adalah di dalam lingkungan yang nomal. Di TNPP, pH, suhu, kemasinan, konduktiviti, oksigen terlarut, jumlah pepejal terampai, keperluan oksigen biologi and klorofil-*a* direkod masing-masing dalam lingkungan 8.09 - 8.97, 29.12°C - 32.06°C, 28.56ppt - 30.30ppt, 47.05µS/cm - 53.36µS/cm, 4.26mg/L - 6.70mg/L, 36.60mg/L - 80.53mg/L, 0.38mg/L - 3.19mg/L dan 0.33mg/L - 2.41mg/L. Bagi nutrien pula, nitrit, nitrat, ammonia dan fosfat masing-masing dalam julat 0 – 0.03mg/L, 0 – 0.05mg/L, 0 – 0.02mg/L dan 0 – 0.01mg/L. Manakala, parameter kualiti air di Manjung merekodkan pH suhu, kemasinan, konduktiviti, oksigen terlarut, jumlah pepejal terampai, keperluan oksigen biologi dan klorofil-*a* masing-masing berada dalam julat 6.99 - 8.50, 30.14°C - 32.76°C, 25.39ppt - 29.62ppt, 44.69µS/cm - 51.85µS/cm, 4.87mg/L - 6.96mg/L, 26.88mg/L – 63.46mg/L, 0.36mg/L - 3.46mg/L dan 0.15mg/L – 1.40mg/L. Untuk nutrien, nitrit, nitrat, ammonia dan fosfat masing-masing berubah dalam lingkungan 0 – 0.03mg/L, 0 – 0.04mg/L, 0 – 0.05mg/L dan 0 – 0.01mg/L. Kepekatan nutrien didapati berkorelasi secara positif dengan kelimpahan obor-obor di TNPP (nitrit, $r = 0.415$, $p < 0.01$; nitrat, $r = 0.263$ $p < 0.01$; ammonia, $r = 0.235$, $p < 0.05$) dan Manjung (nitrit, $r = 0.246$, $p < 0.05$; nitrat, $r = 0.419$ $p < 0.05$; ammonia, $r = 0.589$, $p < 0.01$). Ini memberikan implikasi bahawa pelepasan air kumbahan, pencemar berasaskan daratan dan aktiviti manusia yang lain mengakibatkan pemuatan nutrien ke dalam perairan persisiran pantai dan berlakunya ledakan obor-obor. Oleh itu, kekerapan ledakan obor-obor di perairan Selat Melaka boleh bertindak sebagai penunjuk terhadap tahap degradasi persekitaran marin akibat daripada aktiviti antropogen.

SPECIES COMPOSITION, ABUNDANCE AND DISTRIBUTION OF JELLYFISH IN THE COASTAL WATERS OF PENANG NATIONAL PARK AND MANJUNG

ABSTRACT

A study of species composition, abundance and distribution of jellyfish population in the Straits of Malacca, Malaysia, was conducted for 14-months around the coastal waters of Penang National Park (PNP), Penang (November, 2009 to December, 2010) and Manjung, Perak (September, 2009 to October, 2010). Towing and scooping methods were used for sample collection using a fishing boat cruising at the speed of approximately 2.5 nautical knots during neap tide. The scooping method used visual observation to detect jellyfish on the water surface. Meanwhile towing method required a custom-made trawl towed behind the boat for submerged jellyfish sample. A total number of 5 jellyfish species from 5 genera were identified, namely: *Phyllorhiza punctata*, *Chrysaora* sp., *Rhopilema* sp., *Chiropsoides buitendijki*, and *Carybdea morbakka*. The dominant *Chrysaora sp.* contributed up to 95.42% (PNP) and 97.66% (Manjung) of the total jellyfish catch. The maximum jellyfish number recorded was 57.07±12.37 individuals/1000m^3 in May, 2010 (PNP) and 475.70 individuals/1000m^3 in October, 2010 (Manjung). A clear seasonal jellyfish blooming was observed in September, 2009 and October, 2010 at Manjung waters. In PNP, no occurrences of jellyfish bloom but their presence were observed throughout the whole sampling periods. Physico-chemical parameters recorded at PNP and Manjung were within the normal ranges. In PNP, pH, temperature, salinity, conductivity, dissolved oxygen, total suspended solid, biological oxygen demand, and chlorophyll-*a* varied between 8.09 - 8.97, 29.12°C - 32.06°C, 28.56ppt -

30.30ppt, 47.05µS/cm - 53.36µS/cm, 4.26mg/L - 6.70mg/L, 36.60mg/L - 80.53mg/L, 0.38mg/L - 3.19mg/L and 0.33mg/L - 2.41mg/L, respectively. For nutrient, nitrite, nitrate, ammonia and phosphate varied between 0 – 0.03mg/L, 0 – 0.05mg/L, 0 – 0.02mg/L and 0 – 0.01mg/L, respectively. Meanwhile, the water qualities parameters in Manjung coastal waters recorded pH, temperature, salinity, conductivity, dissolved oxygen, total suspended solid, biological oxygen demand, and chlorophyll-*a* in the range of 6.99 - 8.50, 30.14°C - 32.76°C, 25.39ppt - 29.62ppt, 44.69µS/cm - 51.85µS/cm, 4.87mg/L - 6.96mg/L, 26.88mg/L – 63.46mg/L, 0.36mg/L - 3.46mg/L, and 0.15mg/L – 1.40mg/L, respectively. For nutrient, nitrite, nitrate, ammonia and phosphate fluctuated within 0 – 0.03mg/L, 0 – 0.04mg/L, 0 – 0.05mg/L and 0 – 0.01mg/L, respectively. The concentration of nutrients was positively correlated with the abundance of jellyfish in the PNP (nitrite, $r = 0.415$, $p < 0.01$; nitrate, $r = 0.263$ $p < 0.01$; ammonia, $r = 0.235$, $p < 0.05$) and in Manjung (nitrite, $r = 0.246$, $p < 0.05$; nitrate, $r = 0.419$ $p < 0.05$; ammonia, $r = 0.589$, $p < 0.01$). This implies that sewage discharge, land based pollutants and other human activities result in nutrient loading into coastal waters and causes jellyfish bloom. Thus, the frequency of jellyfish bloom in waters of Straits of Malacca could act as an indicator for marine environment degradation due to anthropogenic activities.

1.0 INTRODUCTION

Over the last several decades, the population of jellyfish is claimed to be increasing. A number of recent increase in jellyfish population have been documented, for examples in the northern Gulf of Mexico (Graham, 2001); the eastern Bering Sea (Brodeur *et al.,* 2002); the Yangtze Estuary, China (Xian *et al.,* 2005); the east Asian waters, Japan (Kawahara *et al.,* 2006); the northeast Atlantic Sea (Gibbons and Richardson, 2009); at Tokyo Bay and the Seto Inland Sea (Shoji *et al.,* 2010). This increase in population has created numerous problems in terms of ecology as well as economy. However, the status of jellyfish invasion in Malaysia is yet to be considered as a serious threat, as reported cases are mostly due to jellyfish stings.

The occurrence of jellyfish in massive numbers has caused a lot of negative impact on the socio-economy which involves the impediment of fish trawling (Uye and Ueta, 2004), the decrease in catch by artisanal and commercial fisheries (Lynam *et al*., 2005; Pauly *et al.,* 2009; Purcell and Sturdevant, 2001), damage to fishing gears, interruption on the operation of desalination plant (Daryanabard and Dawson, 2008), and damage to the seawater cooling systems of coastal power plants (Mills, 2001).

Jellyfish blooms have been interfering power station operations around the world; for instance, in Japan, China, India, the Gulf of Oman, the Persian Gulf, the Arabian Gulf, Qatar and the United States of America, causing severe power reduction and shutdown (Purcell *et al*., 2007). The most significant impact caused by jellyfish invasion in the Asian region was reported in 1999, whereby a major power plant near Manila, Philippines was clogged up by jellyfish, causing a major power failure in the main island of Luzon, Philippines (BBC news, 1999). The same episode occurred in Chingdao, China during the summer of 2009 whereby nearly one third of the city lost its electric supply (CENN.CN, 2009).

In Japan, the giant jellyfish, *Nemopilema nomurai*, has been causing severe damage to their fisheries (Hitoshi, 2005) and more recently, a fishing boat was sunk in the Chiba prefecture of Japan by this particular species of jellyfish (Sinchew, 2009). Besides Japan, fishery operations in China, Australia, Namibia, France, America, the Persian Gulf, the Gulf of Oman and the Mediterranean Sea were also affected by jellyfish blooms (Purcell *et al*., 2007). The presence of this massive number of jellyfish also causes problem to the aquaculture industry, whereby farmed salmons in Northern Ireland (BBC news, 2007) and other cultured species such as shrimps, trouts and bivalves (Purcell *et al*., 2007) were killed during jellyfish blooms.

Jellyfish play an important role as both predators and competitors. They exert predation and competition pressure on other members of the pelagic environment (Purcell and Sturdevant, 2001). The impact of predation on juvenile fish by jellyfish is negative as juvenile pollock and herring larvae are an important part in the scyphozoan jellyfish's diet (Brodeur *et al*., 2002; Lynam *et al*., 2005). A high diet overlap was observed between scyphozoan jellyfish and commercial fish species such as juvenile walleye pollock, Pacific herring *Clupea pallasi*, larvae of herring, *Clupean harengus*, juvenile pollock and the Pacific sand lance *Ammodytes hexapterus* (Brodeur *et al*., 2002; Lynam *et al*., 2005).

Due to the high clearance potential of jellyfish, fast removal of food availability by these creatures will cause low prey availability for fish larvae, and resulting in poor larval survival (Olesen, 1995). Jellyfish usually out-compete other predators due to their high consumption rate and the ability to respond faster to pulses of food, including the early life stages of many fish species (Purcell *et al*., 1999, Purcell and Arai 2001). An invasive jellyfish species, *Phyllorhiza punctata*, in the Gulf of Mexico was found to have a narrow diet. They compete directly with the native jellyfish species, *Stomolophus meleagris*, for the same prey species and thus, causing a reduction in the number of native species (Graham *et al*., 2003b). *P. punctata* also consumes engraulid-type fish eggs and has negative impact on anchovies' recruitment in the Gulf of Mexico. Therefore, jellyfish's predation on eggs and larvae of commercially important fish and shellfish species has indirectly caused losses in the economy (Graham *et al*., 2003b).

Jellyfish blooms in the coastal waters also affected tourism industry. Jellyfish pose stinging hazard to swimmers and this undoubtedly affects the tourism industry (Purcell *et al*., 2007). Jellyfish blooms are also a threat to the coastal power plants which rely on saltwater input to cool down their machinery (Purcell *et al*., 2007). The ingression of jellyfish clogs the sea water intake screen and induces water blockage, resulting in the overheating of machinery (Masilamoni *et al*., 2000). A long list of power plant clogging incidents was reviewed by Purcell *et al*. (2007), showing that jellyfish is causing significant power loss and economic dent to affected nations.

In Malaysia, jellyfish blooms have caused problems in the tourism industry and poses threat to the operation of power plants (Masilamoni *et al*., 2000; Purcell *et al*., 2007). Penang, located at the northern part of Malaysia in the vicinity of the Straits of Malacca, was alarmed when numerous reports were made by tourists concerning jellyfish stings (Malaysiakini, 2010). Langkawi Island, located to the north of Penang, reported its first fatality when a tourist died after being stung by a box jellyfish (Simpson, 2010). With all these grave concerns, clarification of the mechanism of jellyfish blooms and the effects of environmental conditions on jellyfish abundance are indispensable for forecasting and regulating the bloom. The presence of a particular jellyfish species in an area needs urgent identification as well, since some possess fatal venomous sting (Heeger *et al*., 1992).

A lot of speculations have been made and yet, figuring out the main factor of jellyfish blooms is still a challenge. A healthy ecosystem requires a balanced predator and prey dynamics. Removal of any trophic level will offset the balance and consequently leads to major shifts in the food web (Williams, 2009). Overfishing of commercial species such as red tuna and swordfish (the major consumer of jellyfish), have left them with no natural predators which help to control jellyfish numbers (Purcell *et al*., 2007). Also, the removal of food competitors, the sardine and whitebait, have left these jellyfish with numerous resources that allow them to reproduce uncontrollably (Richardson *et al*., 2009). Climate change, which results in global warming, is another factor might affect some of the jellyfish population. Warming of the sea surface temperature might provide more food resources for jellyfish thus, improving the jellyfish survival rate (Mills, 2001). Warmer temperatures is also claimed to favour jellyfish, in terms of in reproduction and providing a better environment for the survival of jellyfish juvenile (Purcell *et al*., 1999).

Moreover, there are evidences that suggest that human activities have contributed to the outbreaks of certain jellyfish species. Coastal eutrophication caused by the addition of excessive nutrients encourages plankton blooms, which act as jellyfish food resources, which may eventually lead to massive jellyfish outbreaks (Purcell *et al*., 2001). Besides, the translocation of jellyfish species through the exchange of ballast water or fouling on ship hulls has assisted the introduction of alien jellyfish species into new marine area (Graham and Bayha, 2007). The introduced species may adapt better than the native species resulting in the explosion of alien species population (Daskalov *et al*., 2007). Other than that, intensive coastal development has also provided a more suitable habitat for jellyfish polyp that encourages polyp proliferation as hard substrates are required for polyp settlement (Graham, 2001; Lo *et al*., 2008). Therefore, the increasing human effects on coastal environment will contribute more to jellyfish blooms (Purcell *et al*., 2007).

The Straits of Malacca is one of the world busiest straits which connects the Indian Ocean to the South China Sea. Sandwiched by the west coast of Peninsular Malaysia and the east coast of Sumatera Island of Indonesia, it is surrounded by heavily urbanized areas with extensive industrial and agricultural development, receiving significant freshwater run-offs from watersheds (Chua *et al.*, 2000). The Straits of Malacca is vulnerable to pollutions as it subsequently receives discharges from land-base and sea-base activities (Hii *et al*., 2006). Two significant sites here were selected for this study namely, Penang National Park (PNP), Penang (located at the northern part of the Straits of Malacca); and Manjung, Perak (the middle region of the Straits of Malacca).

Both of the selected coastal waters have different locality significance and play a different socio-economic role to the society. PNP is a gazetted national park under the National Parks Act No. 226 of 1980 in April, 2003. The land activity is kept at its minimum level though inshore fishing activities are still actively taking place in the coastal waters of PNP. Over-fishing is the potential threat that might have an impact towards the coastal ecosystem of PNP. As it is famous for its beaches and water activities, the presence of jellyfish in the coastal waters is definitely a nuisance to both visitors and tour operators. Although there has been no serious or fatal jellyfish attack reported locally, the unpleasant stinging does affect the tourism industry as it concerns safety issues. Also, fishermen have to deal with the nasty stingers when the jellyfish are trapped in their fishing nets especially during the blooming season, as the trapping of a massive number of jellyfish will damage their fishing nets.

Meanwhile, Manjung's coastal waters have a higher risk of experiencing negative impact resulting from human activities. The coastal area chosen for sampling is adjacent to Sultan Azlan Shah Power Station (SASPS) owned by Tenaga National Berhad (TNB). A fishing village is located closely to SASPS, where the coastal water of SASPS is their fishing ground. The threats imposed by human activities towards the coastal ecosystem are observable; for example, direct discharge of chlorinated warm water from SASPS after the cooling process, potential leaking of coal waste into the surrounding, input of sewage from local community, and over-fishing, all of which might lead to environmental degradation. In Manjung coastal waters, jellyfish ingression is considered as a serious problem to the power plant operation, as clogging of the cooling system by jellyfish will lead to the shutdown of SASPS, which in turn will result in the shortage of power supply.

With the understanding of the seriousness of this issue, this study aims to provide a baseline data for jellyfish distribution and abundance in the Straits of Malacca (SOM). The outcome of this study could be used as a tool to evaluate the impact of anthropogenic factors on jellyfish blooms in tropical regions. With no precedent study, this study is believed to be the pioneer in this region, besides acting as the platform to understand the interactions between jellyfish and both environmental and anthropogenic factors. The baseline information also provides assistance for further investigations in jellyfish population, and serves as a research platform which enables other scientists to develop a deeper understanding of this organism in this region. By conducting a monthly intensive trawl survey for more than one year, the distribution and abundance of jellyfish species were determined. Furthermore, biomass and size structure were obtained in order to aid the interpretation of the demography of jellyfish populations in the Straits of Malacca. The water quality data collected from the sampling locations was used to analyse the association of the environmental factors leading to the jellyfish blooms mechanism.

1.1 Objectives

The objectives of this study are as follows:

a. To determine the species composition, distribution and abundance of jellyfish in the coastal waters of the Penang National Park, Penang and Manjung, Perak.
b. To analyze the effects and influences of the monthly water qualities on the distribution and abundance of jellyfish species in the coastal waters of the Penang National Park, Penang and Manjung, Perak.
c. To investigate and interpret the interaction of anthropogenic and other related factors with the occurrence of jellyfish bloom.

2.0 LITERATURE REVIEW

2.1 Life History of Jellyfish

The term “jellyfish” refers to a taxonomically diverse group of plankton with large, translucent bodies. Jellyfish are passive swimmers belonging to the phylum Cnidaria. They can be differentiated morphologically or represented namely by the classes, Hydrozoa, Scyphozoa, Staurozoa and Cubozoa. There are approximately 200 species of marine Scyphozoa, 700 species of Hydromedusae, 15 species Cubozoa, 12 genera of order Salpidae, and 150 species of Ctenophores have been identified. The class Scyphozoa is known as the true jellyfish that possess stingers and bell-shaped body as an adult; for example, *Chrysaora* spp., *Phyllorhiza* spp., and *Rhopilema* spp., which are usually found in tropical, temperate and cold waters (Bouillon, 1999; Mianzan 1999; Mianzan and Cornelius, 1999).

Cnidarians generally exhibit two body forms: a cylindrical polyp form which needs firm substrate for attachment at its aboral end; in comparison with the other form; medusa, or, more commonly known as jellyfish, which has a very thick, gelatinous mesoglea and lacks skeletal support. They do not have a respiratory system and their body is oxygenated by the diffusion process through their thin skin (Dunn, 1982). Jellyfish have a series of hollow or solid muscular tentacles extending from the margin of the bell and armed with nematocytes. In addition, some species also have oral tentacles rising from the manubrium, from the extended lips of the mouth, or that the mouth may be drawn out into oral arms (McConnaughey, 1970) (Figure 2.1).

The majority of jellyfish species (Hydrozoan, Scyphozoan and Cubozoan) occur in two life stages. By asexual budding, polyps (sessile stage) reproduce and later transform to jellyfish (planktonic stage). From the planktonic jellyfish stage, a jellyfish will then undergo sexual reproduction to produce gametes, which will later form polyps (Arai, 1997; Bouillon, 1999) (Figure 2.2). They are diecious, in other words, they generate gametes with opposite sex, which will later give rise to small ciliated solid-bodied planula larvae. Almost all jellyfish have a short life span and it may vary from a few hours to several months. One particular jellyfish species, *Turritopsis dohrnii*, is known to have a life span of 30 years. This species is considered to be unnaturally "immortal" as it is able to transform, from the adult jellyfish, (planktonic stage), back to the polyp, sessile stage (Miglietta and Lessios, 2009).

Latitude and temperature also play a great role in the jellyfish reproductive cycle. Latitude is the determining factor of the reproductive cycle of jellyfish (Arai, 1997). Temperate and cold water species often reproduce annually during spring or summer when the temperature is warmer, while tropical species reproduce almost all year round (Purcell, 2007). Overall, the above life history characteristics give Hydrozoa, Cubozoa, and Scyphozoa the advantages to reproduce, grow rapidly and form large blooms (Purcell, 2007).

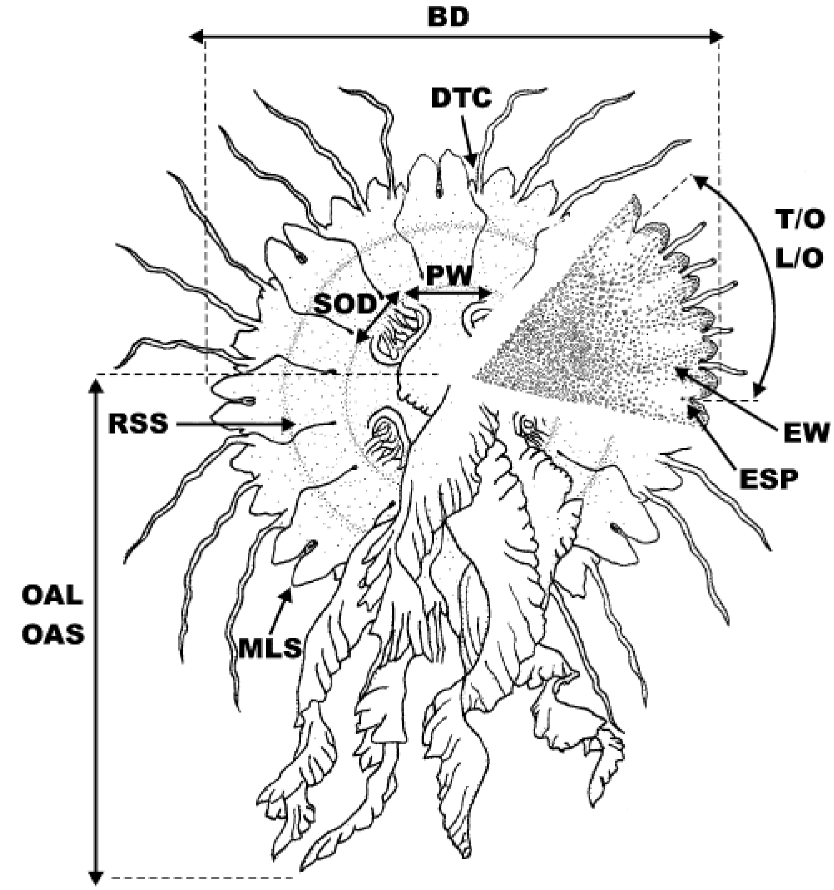

Figure 2.1. Schematic subumbrellar view of a *Chrysaora* medusa (Scyphozoan, the true jellyfish), with oral arms, tentacles and gonads. Schematic exumbrellar view (top right) (Reproduced from Zootaxa 1135 with permission of Magnolia Press). Note morphological features and measurements performed: BD = bell diameter; DTC = depth of tentacular cleft; ESP = exumbrellar sensory pit; EW = exumbrellar warts; L/O = lappets per octant; MLS = marginal lappets shape; OAL = oral arms length; OAS = oral arms shape; PW = pillar width; RSS = radial septa shape; SOD = subgenital ostium diameter; T/O = tentacles per octant (Morandini and Marques, 2010).

The understanding of both jellyfish sessile polyp and planktonic medusa's life history phases would provide a better understanding over the trends of jellyfish population abundance (Mills, 2001). However, much attention was given to the ephyrae and adult medusa stages (Purcell *et al*., 2007). Most recently, the need of examining the benthic stages is being recognized and mostly centered on the sequence from planulae settling through polyps and scyphistomae to strobilation (Purcell, 2007). A recent study by Arai (2009) showed that podocysts do have potential significance for the formation of scyphozoan blooms. This formation of podocysts contributes to higher polyp's proliferation and the ability to survive, especially when food is scarce or to avoid predation.

Meanwhile, Hydrozoan order Siphonophora have a contrasting life history compared to the majority of Hydrozoa and Scyphozoa (Purcell, 2007). Siphonophores do not go through sessile stage, but instead reproduce through asexual and subsequent sexual reproduction of medusa. Most Ctenophores are hermaphrodites and they reproduce via direct development at high rates of fecundity (Mianzan, 1999; Pugh, 1999). Members of the Order Salpidae also have a comparatively contrasting life history. The ability of salp to produce hundreds of decedents from a single asexual oozooid with high growing rates (the highest among metazoans), and short generation times varying from 50 hours to 15 days between reproductive cycles which allow salps to increase rapidly in response to periodic food supply (Esnal and Daponte, 1999).

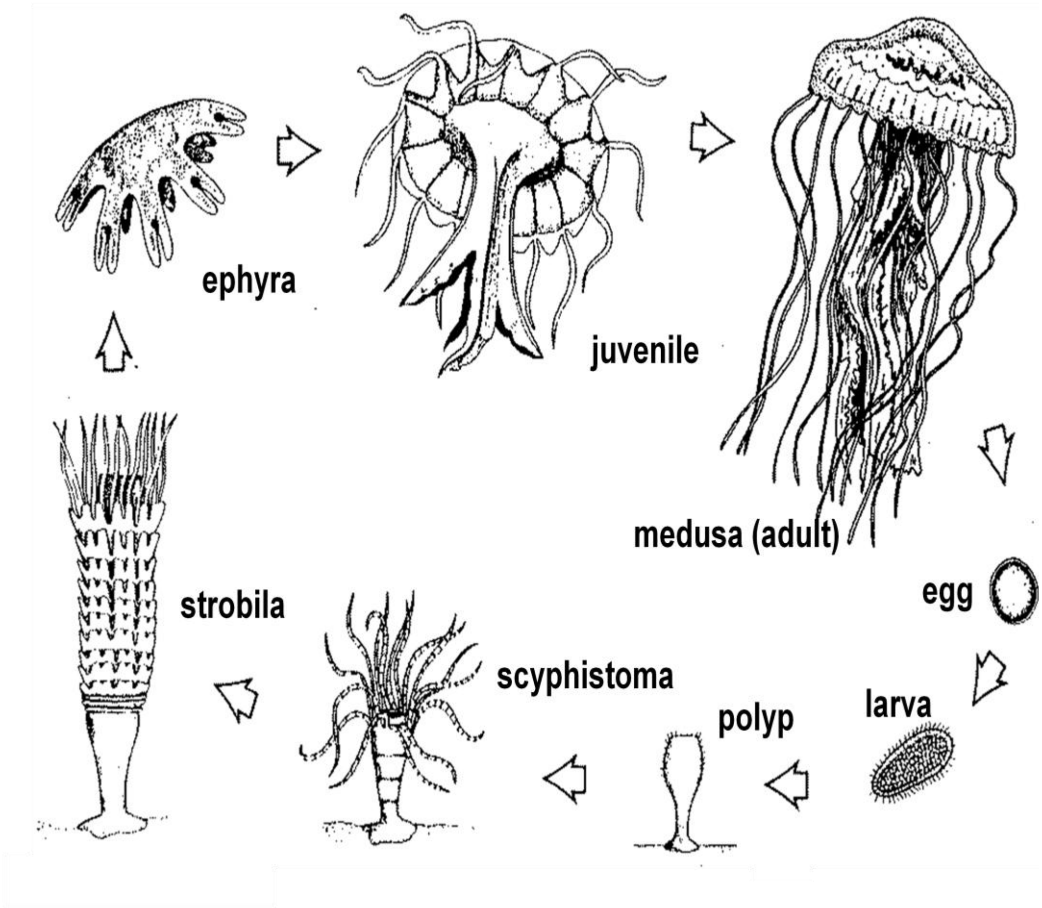

Figure 2.2 Schematic diagram of general Scyphozoan, *Chrysaora* sp., life history (Stippling indicates shadows, not pigmentation) (Bryant and Pennock, 1988).

2.2 Jellyfish Population in World Ocean

Many studies have documented an increasing trend of jellyfish abundance in most parts of the world's ocean with some exceptions showing that certain locations have experienced a collapse in the local jellyfish population (Mills, 2001). The record of abundance available for the scyphomedusan, *Pelagia nocticula*, in the Mediterranean Sea has been documented for over 200 years. Goy *et al*. (1989) showed that the recurrence of *P. nocticula* takes a period of 12 years. The conditions that favour the blooming of *P. nocticula* are temperature higher than 10°C during winter or lower than 27°C in the summer, and the salinity ranged between 35 ppt to 38 ppt (Purcell *et al*., 1999). In the estuaries and coastal waters of the eastern United States, the abundance of *Mneniopsis lediyi* was higher in later years compared to the earlier decades. The range of abundance increased from 5 to 7 individuals m^3 to 60.5 to 350 individuals m^3 (Bayha, 2005). The blooming of this species was found to be correlated with warm spring temperatures, with the range of 7.5°C - 8.5°C to 11.3°C - 14.7°C in Chesapeake Bay (Purcell *et al*., 2001).

Chrysaora spp., also known as sea nettles, are widely distributed from temperate to subtropical coastal waters in the North and South Atlantic as well as South-East Asia (Kramp, 1961). In Namibia, Benguela Current and Southern Africa, the infestation of *C. hysoscella* has severely caused negative impact on their fishery industry (Sparks *et al*., 2001). *C. hysoscella* stranded on the beaches in the Irish and Celtic Sea recorded an abundance of 0.11 individuals per $1000m^2$ (Doyle *et al*., 2007). An overall increase in *C. quinquecirrha* number was also observed in the northern Gulf of Mexico, with a distributional expansion away from the shore (Graham, 2001); whereas *C. fuscescens* was most abundant in the California Current, with the highest recorded amount of 77 individuals per $1000m^3$ (Suchman and

Brodeur, 2005). In the western Bering Sea, the overall abundance of jellyfish increased from 1.1 - 1.8 billion individuals in the summer, to 4.4 - 4.7 billion individuals in fall; whereby *C. melanaster* constituted up to 97% of the total mass (Zavolokin *et al*., 2008). *C. quinquecirrha* on the other hand can tolerate salinity as low as 5 ppt and flourish in the range of 10 ppt to 12 ppt (Cargo and Schultz, 1967). In Cheasapeake Bay, Purcell *et al*., 1999 suggested that the population of *C. quinquecirrha* may be restricted within the salinity range of 5 ppt to 25 ppt. In support of this statement, Brown *et al*. (2002) reported that frequent occurrence of *C. quinquecirrha* was concurrent with the salinity within 10 to 16 ppt and temperatures of 26 ºC to 30 ºC in the summer.

Aurelia aurita and *Aurelia labiata*, commonly known as moon jellyfish, are studied widely due to its ubiquitous nature (Olesen *et al*., 1994; Uye and Ueta, 2004; Shoji *et al*., 2010). The constant occurrence of these species have been documented in many parts of the world ocean: Gullmar Fjord on the Fjord on the Swedish west coast (Grondahl, 1988), the Black Sea (Mutlu, 2001), northern California Current (Suchman and Brodeur, 2005), the Irish and Celtic Sea (Doyle *et al*., 2007), the tropical lagoon of Taiwan (Lo and Chen, 2008), a small shallow fjord at Kertinge Nor, Denmark (Olesen *et al*., 1994) as well as the Seto Inland Sea and coastal waters along western Shikoku, Japan (Uye *et al*., 2003).

In the Black Sea, *A. aurita* was found distributed in patches, with varying abundance from 2 to 14 individual per m^2 in late spring and summer (Mutlu, 2001). In the Irish and Celtic waters, *A. aurita* was lower in abundance with only 0.33 individual per $1000m^2$. Doyle *et al*. (2007) suspected that the hydrographic regime of Irish and Celtic waters is not favourable for jellyfish survival. Whereas densities of *A. labiata* in North California Current reached 10 individuals per $1000m^3$ during June and August of 2000 and 2002 (Suchman and Brodeur, 2005). A combination of physical processes such as weak surface flow, vertical migration, and location of breeding ground, has resulted in such distributional pattern in North California Current (Suchman and Brodeur, 2005). In some waters, the abundance of *A. aurita* could occur in extremely massive numbers. During 1991 and 1992, an excessive abundance of *A. aurita* was recorded in Kertinger Nor, Denmark with a maximum density of approximately 300 individuals per m^3, due to the protected fjord geographical nature (Olesen *et al*., 1994). Meanwhile, Uye *et al*. (2003) attributed the high observed aggregations of *A.aurita*, 250 individuals per m^2, in the coastal waters of the western part of the Seto Inland Sea to the water current rather than biological factors. Another report by Lo and Chen (2008) showed that during the dry season, *A. aurita* occurred in huge numbers in the inner and central parts of eutrophic tropical lagoon in Taiwan, with the maximum abundance of 328 individuals per m^3.

Phyllorhiza punctata is a popular jellyfish species well known for its invasive character (Bolton and Graham, 2004). It is indigenous to the tropical western Pacific waters and is distributed from Australian waters to Japanese waters (Heegar *et al*., 1992; Graham *et al*., 2003a). It was first described by Mayer (1910) in the eastern Australian waters and for that, it is commonly known as the Australian spotted jellyfish. This species was found only in Indo-pacific waters before the 1950s, but ever since has been reported in other parts of the ocean out of its origins (Graham *et al*., 2003a). In 1955, *P. puncatata* was first observed off the Brazilian coast; and recurring population was later reported by da Silveira and Cornelius (2000) in the state of Bahia. Numerous sightings were also reported along the coast of Parana and Santa Catarina in late 2001 (Haddad and Junior, 2006). *Phyllorhiza punctata* was sampled in Laguna Joyuda, Puerto Rico for one year from October 1985, with a maximum numerical abundance of 143 individuals per $1000m^2$ (Garcia, 1990); and its presence was also reported in South California waters (Larson, 1990).

Phyllorhiza punctata has expanded its territory to almost every part of the world ocean. It was reported to be present in the Gulf of Mexico (United States of America), with the average density reaching 2.35 individual per m^2, and an estimated abundance totaling up to a few millions (Graham *et al*., 2003a). After that, *P. punctata* has reappeared along southern Louisiana, off Florida east coast, off Mexican coast, Laguna de Mandinga, off Mediterranean coast of Israel, and the Ionian Sea, Greece. (Graham *et al*., 2003; Abed-Navandi and Kikinger, 2007; Ocana-Luna *et al*., 2010).

Cyanea sp. is a localised jellyfish species present in the Niantic River, Connecticut, the United States of America (Colin and Kremer, 2002). Presence of *Cyanea* sp. was also recorded in the Gullmar Fjord on the Swedish west coast (Grondahl, 1988), the Irish and Celtic Seas (Doyle *et al*., 2007), Puget Sound, Washington (Reum *et al*., 2010); and Southern Brazil (Junior *et al*., 2010). In 2002, blooming of *Crambionella orsini* occurred throughout the Gulf of Oman and the Persian Gulf with a maximum biomass of 123.4 ± 9.9kg per km^2 at the depth of 10 to 20 meter (Daryanabard and Dawson, 2008). In certain Norwegian fjords, the abundance of *Periphylla periphylla* (20 to 320 individuals per m^2) was higher compared to the open ocean environments (Sornes *et al*., 2007). Also, presence of *Nemopilema nomurai* in huge numbers caused damage to local fisheries in Japan (Hitoshi, 2005); and in Korea, outbreak of this jellyfish occurred around Jeju Island, with the highest recorded abundance in 2006 of 948 x 10^{-4}individuals per m^2.

Chudnow (2008) did a summary on jellyfish population of 13 marine ecosystems worldwide. Out of the 13 systems, 10 systems (the Bering Sea, Gulf of Alaska, North Sea, Black Sea, Gulf of Mexico, Gulf of St. Lawrence, Azov Sea, Mediterranean Sea, Namibia and Antarctica waters) experienced an increase in jellyfish abundance with percentage ranging from 0.01 to 0.81. Although all the evidences shown above indicated either an increase or a new discovery of jellyfish population in a certain location, these projected evidences do not represent the whole marine ecosystem. A decrease in jellyfish abundance and species richness was reported in northern Adriatic (Benovic *et al*., 1987); St. Helena Bay, west coast of South Africa (Buecher and Gibbons, 2000); Washington State and British Columbia (Mills and Rees, 2000); southern Black Sea (Mutlu, 2009); and Hiroshima Bay, Japan (Shoji *et al*., 2010). Gibbons and Richardson (2009) showed that in the Atlantic Sea, only marked cycles of peaks and troughs present but not significant increase in jellyfish population.

The presence of jellyfish in Malaysian waters is clearly evident, but scientific reports on its abundance and distribution are lacking. The most recent jellyfish species documentation available in Malaysian waters was done by Fenner (1997), whereby 10 species of medusa (*Acromitoides* sp., *Aurelia* spp., *Carybdea rastoni*, *Cassiopeia* spp., *Catosylus* spp., *Chironex fleckeri*, *Chiropsalmus quadrigatus*, *Chiropsoides buitendijki*, *Cyanea* spp., *Lobonema* spp., *Rhopilema* spp. , *Sanderia malayensis*, *Thysantostoma flagellum*, *T. loriferum* and *T. thysanura*) were recorded. Meanwhile, a preliminary study by Sim *et al*. (2009) showed that there were six jellyfish species, namely: *Phyllorhiza punctata*, *Chrysaora* sp.1, *Chrysaora* sp.2, *Chrysaora* sp.3, *Nemopilema* sp.1 and *Nemopilema* sp.2, present in the coastal waters of Penang National Park. A recent outbreak of jellyfish in Langkawi Island, Kedah and Manjung, Perak were recorded through personal communication and no formal abundance reports are available.

2.3 Ecological Role of Jellyfish

Jellyfish have survived in the world's oceans for over 500 million years. The importance of jellyfish in marine ecosystems has often been overlooked and ignored due to difficulty in sampling and identification. The presence of jellyfish is unique as they are the major zooplankton consumer in the marine ecosystem (Lo and Chen, 2008). The main diet of various jellyfish taxa mostly consists of copepods (Purcell, 1992; Turk *et al.*, 2008), but may also include meroplankton (Purcell, 2003), ichthyoplankton (Purcell and Arai, 2001), and gelatinous plankton (Pauly *et al*., 2009). The zooplankton in the coastal waters of Straits of Malacca mainly consist of copepod (more than 70%) and this provides a plentiful of food sources for jellyfish (Rezai *et al*., 2009).

A few studies also indicated that jellyfish play an important role in controlling zooplankton population and sometimes, act as a keystone species that exert predation pressure on the zooplankton population (Olesen, 1995). For example, the blooming of *Noctiluca scintillans* was caused by the grazing activity of jellyfish towards herbivorous mesozooplankton which generally out-competed *N. scintillans* for diatom prey (Pitt *et al.* 2007). It was also shown through the high consumption rate of jellyfish towards larvacean species in Prince William Sound (Purcell, 2003), multiple negative effects of *Chrysaora quinquecirrha* on *Mnemiopsis lediyi* (Purcell and Cowan, 1995), predation pressure on euphausiid over the inner-shelf off Oregon (Ruzicka *et al*., 2007) and also the recognition of scyphomedusae and ctenophores as an important predators of bay anchovy eggs and larvae in the mesohaline region of

Chesapeake Bay (Purcell *et al*., 1994). Hence, there are evidences showing that jellyfish sometimes act as a keystone species in an ecosystem.

Each jellyfish species also plays a role in sustaining the availability of prey population through intraguild predation. It occurs when jellyfish prey on other species of jellyfish, which in turn gives space to the survival of their common prey species (Feigenbaum and Kelly 1984; Purcell, 1991). Pierce (2005) also pointed out that gelatinous prey is a good dietary supplement for gelatinous predator. On top of that, Costello and Colin (2002) concluded that prey encounter and capture mechanism do play a part in determining the trophic role of the particular jellyfish species.

Other than being the voracious predator, jellyfish is potentially important as competitors for zooplankton preys (Purcell and Arai, 2001). A high dietary overlap observed among crustacean-eating pelagic coelenterate and forage fish species supported the fact that potential competition exists (Purcell and Sturdevant, 2001). By attaining a high biomass in the ecosystem, jellyfish is likely to be an important energy pathway in diverting zooplankton production away from zooplanktivorous fishes (Lynam *et al*., 2006). The fish larvae of commercial fish species such as herring, rockfish, cod and flatfish may also be affected by jellyfish predation (Schneider and Behrends, 1998; Purcell, 2003).

Jellyfish have the potential to reduce the efficiency of the entire ecosystem by diverting energy from prey population and increasing the level of competition. According to Lo and Chen, 2008, when they occur in large numbers, it may lead to the reduction of zooplankton (particularly copepods) populations and indirectly cause phytoplankton blooms. Due to an extraordinarily high consumption rate, jellyfish are claimed to be capable of exerting considerable control over the flow of energy and nutrients through the ecosystem, especially when they are present in massive number (Graham, 2001). Pitt *et al.* (2007) managed to obtain the data which link jellyfish to the formation of red tides, and also showed that the presence of jellyfish does cause changes in the phytoplankton assemblages. The ecosystem of the western Baltic Sea also experienced a recorded alteration in both zooplankton composition and phytoplankton abundance due to the cascade effect resulting from an outbreak of the top predator, *Aurelia aurita* (Schneider and Behrends, 1998).

Other than being the predator, jellyfish also play an important role as the prey species (Arai, 2005). In the Bering Sea, scyphozoan jellyfish are preyed by 11 species of birds (Harrison, 1984). Online databases such as Fish Base and Sea Life Base explicitly describe the role of jellyfish as prey species. Fish Base reported that a total of 124 fish species feed either occasionally or predominantly on jellyfish, and nearly half belongs to the perciform fishes. Whereas, Sea Life Base reported that 34 non-fish marine organisms, mainly reptiles, birds, and crustacean, feed on jellyfish at least occasionally (Pauly *et al*., 2009). Stomach content examination has shown that jellyfish are part of the diet for a wide variety of fish species including some with commercial importance, for example, chum salmon *Onorhynchus keta*, butterfish *Perilus triacanthus*, and spiny dogfish *Squalus acanthias*, all of which were found to prey on jellyfish (Purcell and Arai, 2001; Arai, 2005). Additionally, exclusive jellyfish feeders such as *Stromateus brasiliensis* and *Seriolella porosa*, were found in the Argentine Continental during spring and summer (Mianzan *et al*., 1996).

Jellyfish also contribute passively back to the ecosystem by transferring organic matter to the seabed in faecal aggregates and mucous sheets (Robison *et al*., 2005). This provides a labile food source for benthic organisms (Pfannkuche and

Lochte, 2000) and may also support bacterioplankton production (Pitt *et al*., 2009) after sinking rapidly to the deep sea floor. Mechanisms of jellyfish in which they acquire and recycle carbon, nitrogen and phosphorus, determine the magnitude of influence towards the nutrient cycles (Pitt *et al*., 2009).

Basically, jellyfish can be classified into zooxanthellate (members of the genera *Cassiopea*, *Mastigias* and *Phyllorhiza*) and non-zooxanthellate jellyfish (*Catostylus mosaicus*) (Pitt *et al*., 2009). Zooxanthellate jellyfish have symbiotic microorganisms which undergoes photosynthesis. Jellyfish is most likely to be independent and derive most of their carbon from the translocation of photosynthetic products without releasing nitrogen and phosphorus (or in minimal), besides having the potential to compete with phytoplankton for dissolved inorganic nutrients (Kremer, 2005; Pitt, *et al*., 2005). Whereas non-zooxanthellate jellyfish obtain its carbon, nitrogen and phosphorus through predation on zooplankton, with little contribution from external dissolved organic matters (Ferguson, 1988). Faeces excretion with the contents of ammonia, phosphate, dissolved free amino acids, and dissolved primary amines by non-zooxanthellate jellyfish helps to recycle and regenerate carbon, nitrogen, and phosphorus (Shimauchi and Uye, 2007). Another passive role played by the jellyfish is by releasing nutrients back to the ecosystem through decomposition. The substances from dead jellyfish has a significant importance in the cycling of organic matter in the marine ecosystem, by serving as one of the major carbon sources to the environment (Mills, 1995; Alldredge, 2005; Yamamoto *et al*., 2008; Pitt *et al*., 2009; Tinta *et al*., 2010). This might have an impact on primary production, thus contributing indirectly to jellyfish bloom.

Jellyfish also serve as a refuge from predation for some fish species and juveniles. For example, Walleye Pollock, *Theragra chalcogramma*, use the shelter of jellyfish for protection from larger fish (Brodeur *et al*., 2002). Sheltered fish may feed on the jellyfish's prey and parasites, and jellyfish are likely to be the intermediate vectors for various fish parasites (Hay, 2006). When conditions are critical and the abundance of other preys are low, all life stages of jellyfish may also function as "survival food" to feed other marine organisms (Mianzan *et al*., 2001).

Although jellyfish is often deemed as a nuisance to human, it does undeniably play an important role in the ecosystem. Generally, jellyfish act as the predator that efficiently reduces the population of certain zooplankton species, and to some extent, jellyfish could act as the keystone species that control their prey population. Jellyfish also contribute back to the ecosystem by serving as prey species, by nutrient release when they are alive and nutrient deposit when they are dead.

2.4 Causes and Consequences of Jellyfish Blooms

There has yet a definite reason for jellyfish blooms, but many scientists have speculated that jellyfish blooms are the result of both human activities and climate change. Some evidences indicate that jellyfish abundances fluctuate with climatic cycles (Purcell, 2005). In addition, intensive human activities are also believed to have contributed towards the massive escalation of jellyfish population (Purcell *et al*., 2007).

2.4.1 Nutrient Input

Subsequent receptions of nutrient input from coastal human activities make coastal waters vulnerable to nutrient pollutions (Hii *et al*., 2006), which results in eutrophication (Hashimoto *et al*., 2006). Eutrophication provides additional nutrients which are needed for phytoplankton blooms, ultimately leading to jellyfish outbreaks (Purcell *et al*., 2001). More food are available for jellyfish and their polyps, therefore encouraging the sexual and asexual reproduction of jellyfish (Stibor and Tokle, 2003; Lucas, 2001). According to Harashima *et al*. (2006), nutrients contributed into coastal waters from fertilizer runoffs are mostly consist of high nitrogen and phosphorus content, but lacks silica. This condition favours the blooming of non-siliceous phytoplankton, but not of diatoms. This reduces the size of primary and secondary producers which supports fewer predators and grazers in the food web due to smaller average food size and longer food chain (Cushing, 1989).

With the jellyfish's ability to feed on a wide range of prey (Malej *et al*., 2007), it is claimed to be favourable to jellyfish survival, in comparison with other predatory species (Parson and Lalli, 2002). Studies have shown that jellyfish have extreme tolerance to low oxygen concentrations (Shoji *et al*., 2005; Thuesen *et al*., 2005). *Mnemiopsis leidyi* achieve a higher feeding efficiency in hypoxia, which makes less-tolerant preys (copepods) more vulnerable to predation (Decker *et al*., 2004). Thus, hypoxia in coastal waters allows jellyfish to capture their prey easier, with less competition for prey and space with other predatory fish. Owing to eutrophication, there is an increase in number of suitable habitats available for jellyfish feeding, growth and survival (Richardson *et al*., 2009; Shoji *et al*., 2010).

2.4.2 Habitat Modification

Jellyfish require a hard substrate for their polyps' attachment during their reproduction process. The addition of artificial substrates, for example, concrete blocks, plastic floats, and aquaculture rafts in coastal waters provide extra breeding grounds for jellyfish (Yasuda, 2003). Intensive aquaculture activity along Tapong Bay, Taiwan was believed to be the primary factor that enhanced jellyfish population (Lo *et al*., 2008). The existence of aquaculture rafts provide substrate and shading for larval settlement and colony formation. The rafts also prevented water exchange which enabled nutrients to be accumulated in the lagoon (Lo *et al*., 2008). Whereas, the petroleum platforms in the Gulf of Mexico serve as an extended surface from the seafloor to the surface for polyp settlement. A larger surface area provides polyps with the opportunity to attach at the ideal depth for growth (Graham, 2001). The expansion of economical activities along coastlines and additional fortifications required to withstand future sea-level rises, could further increase the number of suitable breeding grounds for jellyfish (Richardson *et al*., 2009).

2.4.3 Overfishing

Jellyfish are the prey target for some fish species, reptiles, mammals and aves (Pauly *et al*., 2009). The removal of jellyfish predators from the food chain may cause the increase of jellyfish in numbers (Purcell and Arai, 2001). The increase of *Aurelia aurita* in the Black Sea was linked with the disappearance of mackerels in 1960s (Zaitsev and Polischuk, 1984; Zaitsev, 1992). A similar incident was suspected in the Adriatic Sea when the increase of *Pelagia nocticula* was correlated with the reduced population of several predator fish (Parsons, 1995).

Other than removing jellyfish predators, zooplanktivorous fish species that act as prey competitors are also being removed, which resulted in a more abundant food supply available for jellyfish (Purcell *et al*., 2007). Overfishing of locally dominant small filter feeding fish stock lead to major jellyfish bloom due to inadequate replacement for the fished species; for example, anchovy, sardine and herring (Richardson *et al*., 2009). Other studies also indicated the impact of overfishing on increasing jellyfish population as shown by the blooming of jellyfish following filter feeding fish stocks collapse in the Black Sea (Shiganova, 1998), the Caspian Sea (Daskalov *et al*., 2007) and the Bering Sea (Brodeur *et al*., 2008).

2.4.4 Translocation

Advancement of transportation and economic globalization has prompted in alien species introduction and accidentally introduce several species of jellyfish to all around the world (Purcell *et al*., 2007). The most common means of translocation discussed is through the discharge of ballast water containing alien organisms or polyp fouling on ship hulls (Graham and Bayha, 2007). Due to a higher living standard, leisure activities such as aquarium trade, have also contributed to species translocation (Bolton and Graham, 2004). In the Mediterranean Sea, the tropical jellyfish species, *Phyllorhiza punctata*, was suspected to invade from the Red Sea through the Suez Canal (Jarms, 2003). Long distance ferry boats operating at the harbour of Igoumenitsa were also suspected to be the polyp carrier when the highest number of *P. punctata* was recorded (Abed-Navandi and Kikinger, 2007). And the northern Gulf of Mexico was also intruded by the same species, and creating a great deal of ecological and economical concerns (Bolton and Graham, 2004).