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Endocrine Disrupting Chemicals (EDCs) in the Gulf of Thailand: A Review and Identifying Knowledge Gaps

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ABSTRACT

This literature review synthesizes existing information about EDCs and their impacts on organisms in the Gulf of Thailand and surrounding waters, focusing on the chemicals Bisphenol-A, Microplastics, 17β-estradiol, Tributyltin, Phthalate Esters and Metalloestrogens, and their influence on several organisms in the area. Knowledge gaps in current information, especially regarding the Dugong population, with the intent of encouraging future studies, and aiding in the conservation of biodiversity, sustainable development and environmental remediation in the region are outlined. It is imperative that more research is conducted to quantify the level of EDCs present in the Gulf, as well as the impact of certain EDCs on general wildlife. Additionally, more research is also required on the impact of EDCs on vulnerable organisms, such as the dugong, to better inform conservation efforts in the region, and preserve Thailand's impressive biodiversity.

Background

Endocrine-disrupting chemicals (EDCs) pose a potential risk affecting both wildlife and human health on a global scale. In general, EDCs are defined as substances in our environment, food, and consumer products that can disrupt hormonal balance and result in adverse health effects. (Vethaak & Legler, 2013) These adverse health effects are elicited primarily by the interaction of an EDC with an endocrine mechanism, given the right dose and timing of exposure. Recent studies have shown that some EDCs, including natural hormones, pharmaceuticals, some pesticides, and industrial contaminants, can cause developmental, reproductive, neural, immune, and other problems in a variety of wildlife species.

Although Endocrine Disruption in Wildlife is a rapidly developing and evolving area of study, limited information exists on the presence of these chemicals and their impact on organisms in specific geographical locations. One such location is the Gulf of Thailand, a shallow inlet in the southwestern South China Sea, bounded between the southwestern shores of the Indochinese Peninsula and the northern half of the Malay Peninsula. It is home to many famous tourist destinations, notably Pattaya, and the islands of Ko Samet and Ko Samui. The area supports a vital marine ecosystem with a diverse array of marine life, and consists of a variety of different habitats, including Coral Reefs, Seagrass Beds, Mangrove Forests and River Estuaries. Considering its geographical location, the Gulf is a strategic marine hub, and has always been an important connection between East and West international maritime trading and the sea lanes of communication (SLOC). Being Thailand's largest coastal waterway and main oceanic access, the inlet also holds immense economic importance, and contains prominent fisheries and tourism industries. The area hosts a significant petrochemical industry - one of the most well-developed petrochemical industries in Asia, and a major contributor to Thailand's economy, accounting for about 5% of the country's GDP. (*Thailand's Petrochemical Industry*, 2024)

The Gulf of Thailand faces potential contamination from EDCs due to the increasing anthropogenic and industrial activities along its coastline. Multiple studies have detected the presence of EDCs in the area, such as Bisphenol A (BPA) and Tributyltin (TBT). This poses a substantial threat to the impressive biodiversity of the Gulf, which supports over 11,900 marine invertebrate species and approximately 2,100 marine fish species. The presence of EDCs is also a risk for the human population in Thailand - EDCs have been found to accumulate in marine life that are dietary staples for coastal communities, and EDCs entering the Gulf through effluent discharges from the petrochemical industries, which can lead to increased instances of obesity, diabetes, reproductive disorders, and cancers, among other adverse effects.

This literature review aims to synthesize existing information about EDCs and their impacts on organisms in the Gulf of Thailand and surrounding waters, focusing on the chemicals Bisphenol-A, Microplastics, 17β-estradiol, Tributyltin, Phthalate Esters and Metalloestrogens, and their influence on several organisms in the area. It will also outline knowledge gaps in current information, especially regarding the Dugong population, with the intent of encouraging future studies, and aiding in the conservation of biodiversity, sustainable development and environmental remediation in the region.

Microplastics

Plastic is the most prevalent type of marine debris found in the Earth's oceans. It can come in all shapes and sizes, but those that are less than five millimeters in length are defined as microplastics. (*What Are Microplastics?*, n.d.) These miniscule pieces of plastic originate from various sources, such as the degradation of larger plastic items, like plastic bags, bottles, and fishing nets, as well as synthetic textiles, vehicle tires, city dust, plastic pellets, and marine coatings, that require centuries to degrade. Plastic debris in the environment is also eventually turned into microplastics by natural wind, tides, ocean currents, and UV radiation. Additionally, a type of microplastic called microbeads - tiny pieces of manufactured polyethylene plastic - are found in many widely-used personal care products, such as exfoliants and cleansers.

As an emerging field of study, not a lot is known about microplastics and their environmental and health impacts yet. However, substantial knowledge and scientific evidence exists on microplastics acting as carriers and vectors for endocrine disrupting chemicals in the environment, particularly in aquatic ecosystems. Microplastics have also been found to be ingested by a wide range of marine organisms, including fish, shellfish, and other aquatic species. Microplastics can resemble the size, shape, and color of natural prey items like plankton, fish, eggs or larval organisms, which means that many marine animals such as filter-feeding whales and krill, inadvertently ingest microplastic while feeding on their normal prey. Other starving animals may also intentionally consume microplastics, mistaking them for food. The ingestion of microplastics can lead to bioaccumulation and biomagnification of microplastics and associated EDCs in marine species, which poses a threat to higher trophic level organisms and human health.

Thailand has been listed as one of the top 20 countries in terms of annual plastic emissions into the ocean. (SEA circular Project, 2023) Research has shown that microplastics are ubiquitous in the Gulf of Thailand. Specifically, microplastic abundance ranges from 0.02-42.46 particles per cubic meter, with higher concentrations observed during the dry season, compared to the wet season. The precipitation, wind, and current patterns driven by the monsoon season influence the abundance and distribution of microplastics in the region.(Pradit et al., 2024) A diverse range of microplastic polymer types have been identified, and the sources of microplastics are proposed to include plastic waste fragmentation during the dry season, followed by runoff and transport during the wet season. Microplastics can also originate from land-based sources like rivers, urban areas, and coastal activities. These particles have also been detected in the sediments of sensitive coral reef and mangrove environments in the Gulf of Thailand.

The mangrove environment is a significant ecosystem, providing young ocean animals with food and habitat. The mangrove trees also provide natural infrastructure to help protect nearby populated areas by reducing erosion and absorbing storm surge impacts during extreme weather events. Studies about microplastics in mangrove areas reveal that plastic has been buried across the Red Sea and the Arabian Gulf since the 1930s, and has exponentially increased since the 1950s, in line with global plastic production. The mangrove areas in particular have a high sinking potential for sediment load and microplastics, because of their plant root systems and low-energy environments. The results of a preliminary study on microplastic abundance in mangrove sediment cores at Mae Klong River, upper Gulf of Thailand implied that microplastics and microparticles have polluted the mangrove sediment in the Mae Klong River basin, an important fishery area. The research shows that microplastics were found at a 142-cm depth and have accumulated in deep sediment layers in association with microplastic infiltration and biota distribution. The abundance of microplastics increased from deep toward the surface, a trend which is expected to rise in the future. The study concluded that microplastic types in this area were entirely due to anthropogenic activities, and that the microplastics in the mangrove areas may have an adverse effect on the diverse species that inhabit it.(Chaisanguansuk et al., 2023)

Coral reefs too, are crucial in supporting diverse marine life and providing significant economic benefits to communities worldwide. Coral reefs provide millions of habitats, food sources, and livelihoods. The Gulf of Thailand contains approximately 74.8 square kilometers of coral reefs, which account for 10% of the world's total coral reef area. Moreover, these waters are home to over 400 coral species. A literature review titled "Microplastic as an invisible threat to coral reefs : Sources, toxicity mechanisms, policy intervention, and the way forward " extensively discusses the detrimental impacts of the abundance of microplastics on these fragile ecosystems. It acknowledges that the issue of microplastic pollution in marine environments has gained considerable attention in the scientific community. Previous research that shows that microplastics can have a monumental impact on the well-being and longevity of coral reef ecosystems, as well as concerns regarding the long-term viability of these ecosystems. More research is required on the spatial variation and sources of microplastics in coral reefs, but it is understood that microplastics can accumulate in high concentrations in the water column and on the seafloor. Similar to the mangrove environments, a main concern with the abundance of microplastics is their widespread utilization, hydrophobic nature, small size, and extended lifespan. These properties may allow them to act as vital transporters for different hazardous substances linked to them, such as organic chemical compounds and toxic metal contaminants, which in turn could act as endocrine disrupting chemicals for marine species. Microplastics can also physically damage tissue, reduce growth and reproduction, and alter the behavior of associated coral species, which can negatively impact entire marine ecosystems and food webs. In addition, microplastics can act as carriers for toxic chemicals and pathogens, which can be transferred to coral reefs and cause harm to the organisms that reside there. Microfiber objects have been found to damage coral tissues physically, provide entry points for viruses and ciliated protozoa, and cause pathological conditions. The impact of microplastics on corals requires immediate attention, as it is complex and multi-faceted, and may involve instantaneous and unforeseen consequences. The need of the hour is to thoroughly understand the prevalence, origins, and risks of MP particles in coral reef environments.(Rahman et al., 2023)

The chemical composition of microplastics enables them to act as notable endocrine-disrupting chemicals. They often contain or absorb EDCs, such as bisphenols, phthalates, and heavy metals, chemicals which are typically used in plastic production. These chemicals can leach from the microplastic particles, and interfere with hormonal systems. Microplastics and their associated chemicals can also have structures similar to natural hormones, allowing them to bind to hormone receptors and disrupt normal hormonal signaling. This can in turn lead to inappropriate activation or blocking of hormone receptors, resulting in altered physiological responses. Additionally, microplastics can absorb various harmful chemicals from the environment, acting as vectors that facilitate the transfer of endocrine disrupting chemicals into biological systems. This property increases the bioavailability of harmful substances when an organism ingests microplastics.

A recent study conducted in the upper Gulf of Thailand investigated the prevalence of microplastic contamination in edible marine fishes. The study found that 46.9% of the sampled fish contain microplastics in their gastrointestinal tracts, with an average of 1.6 ± 0.5 pieces per fish. Demersal species exhibited higher contamination rates compared to pelagic species. The predominant types of microplastics identified were fibrous and blue-colored materials, with polyester and polyethylene being the most common polymers detected. Notably, the research indicated that while no direct associations were found between microplastic presence and histopathological changes in fish tissues, the potential for microplastics to act as carriers for harmful chemicals that could potentially act as EDCs, remains a frightening reality. The authors of this study emphasize the risk of microplastic ingestion for humans through seafood, and recommend ongoing surveillance of microplastic levels in the marine food chain to safeguard seafood safety and the marine ecosystem in the Gulf of Thailand, while highlighting the need for further studies to explore the interactions between microplastics and EDCs, as well as their cumulative effects on marine life and human health. (Srisiri et al., 2024)

Similarly, a study titled "Surveillance and histopathological study of microplastics in marine fish from the Gulf of Thailand" investigates the prevalence and impact of microplastics in marine fish, which are significant to the local food chain and human consumption, but also important to marine ecosystems. The research found that microplastics were present in the gastrointestinal tracts of 46.86% of the sampled fish, with an average of 1.556 pieces per fish. No microplastics were detected in the muscle, liver, kidney or gonads of the fish, indicating a selective accumulation in the digestive system. The study highlighted that benthic fish exhibited higher contamination levels compared to pelagic species, with fiber-type microplastics being the most commonly observed. The predominant polymers identified were polyester and polyethylene, with polyester being more prevalent in benthic fish. Moreover, the study concluded that the presence of microplastics did not correlate with any histopathological lesions in the fish, suggesting that while microplastics are a concern, their immediate health impacts may be limited. However, more research must be conducted on the correlation between microplastics and disruption of hormones in fishes is required to provide more clarity on the endocrine disrupting mechanisms of microplastics. The authors of this study also emphasized the need for ongoing surveillance to assess the long-term implications of microplastic consumption on both human health and marine ecosystems. (Srisiri et al., 2020)

The findings of a study on Microplastic Accumulation in Catfish and its Effects on Fish Eggs from Songkhla Lagoon, Thailand, provides valuable insights in the detrimental effects of microplastic and its associated endocrine disrupting mechanisms on these organisms. The study found microplastic contamination in soldier catfish, or *Osteogenesis militarus* from Songkhla Lagoon and the U-Taphao canal, with highest levels in the stomach, followed by tissue and gills. Fibers were the dominant microplastic shape found in organs and fish eggs. Moreover, Fibers were the dominant microplastic shape found in organs and fish eggs - of 349 fish eggs examined, 27 microplastic items were found. Common polymer types detected were polyethylene terephthalate, polypropylene, and cellulosic fibers. The study also stated that they discovered microplastics in every organ of the studied fish, which is an alarming statistic and a call for action to fight microplastic pollution in our oceans. The authors note that microplastic may have contaminated the fish eggs, and their results provide baseline data on microplastic pollution in biota from the region. Given our current knowledge on microplastics as an endocrine disruptor and vector for endocrine disrupting chemicals, the possible contamination of catfish eggs with microplastics is a massive concern and could be having significant negative effects on the hatched offspring. (Pradit et al., 2023)

A study titled "Bioaccumulation of Microplastics in Fish and Snails in the Nam Pong River, Khon Kaen, Thailand", investigates the accumulation of microplastics in two fish species, *Barbonymus altus* and *Laides longibarbis,* as well as two snail species, *Filopaludina martensi* and *Pomacea canaliculata*. The research highlights significant findings regarding microplastic ingestion and its implications for aquatic life in the Nam Pong River, a crucial water source in the region. Specifically, the findings quantified the microplastic accumulation in these species. The average microplastic accumulation in the gastrointestinal tracts of *B. altus* was 25.42 ± 26.50 pieces per fish, while *L. longibarbis* had 7.60 ± 17.70 pieces. In snails, *P.c canaliculata* showed an average of 26.33 ± 33.30 pieces, contrasting with 11.50 ± 16.60 pieces in *F. martensi.* Notably. *B. altus* exhibited a significantly higher accumulation of microplastics compared to *L.longibarbis*, suggesting that feeding habits influence ingestion rates. The predominant type of microplastic found was high-density polyethylene (HDPE), with 55.47% of the particles being fragment-shaped. The study also noted that microplastics in *P.canaliculata* started at a minimum size of 1 micrometer, indicating a range of sizes present in the environment. The paper also hypothesized that feeding behavior correlates to microplastic accumulation. The findings suggest that omnivorous species, such as *B. altus*, tend to accumulate more microplastics than herbivorous or carnivorous species. This observation aligns with the previous hypothesis that dietary habitats and habitat proximity to pollution sources significantly impact microplastic ingestion rates. Again, with current and expanding knowledge on microplastic as an endocrine disrupting chemical and its endocrine disrupting mechanisms, the bioaccumulation of microplastics in marine organisms is extremely concerning, and it is imperative that further research is conducted on the endocrine disrupting capabilities of microplastics. (Yasaka et al., 2022)

Another study investigated the occurrence of microplastics and trace metals in the stomachs of a species of fish, *Arius maculatus* and 2 types of shrimp, *Parapenaeopsis hardwickii* and *Metapenaeus brevicornis*, from Songkhla Lake, Thailand during the first lockdown period in May 2020, the peak of COVID-19. The average number of microplastic pieces per stomach was 2.73± 0.15 in the species of fish, 4.11±1.12 in *P. hardwickii*, and 3.78±1.12 in *M. brevicornis*. The most common microplastic shapes were fibers, with black being the predominant color, followed by blue, white and red. The size of microplastics varied, and 5 polymer types were identified. The authors suggest the lockdown may have increased microplastic release into the lake from activities like increased laundry, highlighting the positive correlation between anthropogenic activities and microplastic accumulation in the environment. Anomalous correlations were found between microplastic counts and trace metal concentrations in organism tissues. More research is crucial in fully understanding the implication of the occurrence of microplastics and trace metals in the stomachs of organisms on their endocrine systems. (Pradit et al., 2022)

A thesis titled "Extraction and Identification of Microplastics in Green Mussels in Thailand" provides valuable insights on the prevalence and characteristics of microplastics in green mussels, *Perna viridis*, a common food in the Thai diet, sourced from various markets and aquaculture sites in Thailand. The study found a worrying 100% detection frequency of MPs in the sample, with an average abundance at 7.32±8.33 items/mussel and 1.53±2.04 items/g wet weight. The dominant types of microplastics identified included ethylene/propylene copolymer, low-density polyethylene (PE-LD), polypropylene (PP), and polyethylene terephthalate (PET). The majority of the MPs were fragments (75.4%), followed by fibers (24.6%). Significant contamination in aquaculture environments was highlighted, which strongly suggests that green mussels serve as a potential route for human exposure to microplastics, raising concerns about the implications for public health. Given current knowledge on the position of microplastic as endocrine disrupting chemicals and carriers of hazardous chemicals, it is also valid for the scientific community to be alarmed about the impact of the microplastic detection frequency this study demonstrated on the health of green mussels. Additionally, the study identified a lack of correlation between the abundance of MPs in mussels and their surrounding water and sediments, indicating a need for further research to understand the sources and impacts of microplastic pollution in aquaculture systems. It is imperative for more research to be conducted on possible endocrine disruption in green mussels due to the 100% microplastic detection frequency, as this could provide crucial details on the endocrine disrupting mechanisms of MPs and could be used to predict the effects in other similar species and the marine ecosystem. (Hewawasam Udmullage, 2021)

BPA (Bisphenol-A)

Bisphenol-A, or BPA is one of the highest volume chemicals produced worldwide. A building block of polycarbonate plastics often used for food and beverage storage, BPA is also a component of epoxy resins that are used to line food and beverage containers. The chemical can leach from these and other products in contact with food and drink, which explains why much of the world has been trying to move to BPA-free plastics in the past decade. In addition, BPA is a known endocrine disruptor, and emerging evidence is providing previously unknown insights into the actual potency of BPA as an EDC. Moreover, it is hypothesized that BPA may influence multiple endocrine-related pathways, raising concerns as exposure to BPA is ubiquitous.

The toxicity mechanisms of BPA are wide-ranging and complex. Firstly, BPA is a xenoestrogen. While this function of BPA was always known, it was initially considered to be a weak environmental estrogen, based on the relative binding affinity of BPA for the classical nuclear receptors ER alpha and ER beta, which were estimated to be over 1000-10,000 fold lower than that of estradiol. However, currently, BPA is equivalent in potency to estradiol, and can stimulate some cellular responses at very low concentrations, raising concerns given that it is present in high concentrations in our natural environment. Also, some metabolites of BPA may be more potent estrogens than the parent compound, and the EDC has been shown to interact differently than estradiol with the ligand binding domain of the classical estrogen receptors. Differences have also been noted in the recruitment of transcriptional co-regulators, which strongly suggests that BPA is not merely an estrogen mimic, and can impact humans and wildlife to a greater extent. It has also been found to bind to the estrogen related receptor, ERRgamma, with high specificity. Based on their studies of BPA and frog metamorphosis and the conservation of thyroid hormone pathways, Heimeier and Shi have also concluded that BPA may affect human embryogenesis and neonatal development through disruption or inhibition of thyroid hormone pathways, as BPA can bind to the thyroid hormone receptor and act as an antagonist to inhibit transcriptional activity stimulated by thyroid hormones. Other activities of BPA include potentially binding to the human glucocorticoid receptor, and acting as an androgen receptor antagonist, inhibiting aromatase activity which would decrease the conversion of testosterone to estradiol and could have significant implications during development and in adulthood. The extensive adverse effects of BPA in humans suggests that similar toxicity mechanisms can be seen in wildlife, raising concerns as BPA currently exists in high concentrations in the environment and hence ecosystems. (Rubin, n.d.)

Recent research has investigated the levels of bisphenol-A and 17β-estradiol in green mussels, and surrounding water samples from the Gulf of Thailand, focusing on sites near industrial and urban areas. High concentrations of BPA were detected in mussel tissues, with water samples showing maximum levels of 371.13 ng/L in coastal areas and 50.7 ng/L in freshwater sites close to industrial zones, highlighting the ubiquity of BPA in the natural environment. Similarly, elevated E2 levels (62.99 ± 5.03 ng/L) were found predominantly in freshwater sites near urban areas, indicating significant contamination sources. The study also found that mature green mussels (over 6 months old) exhibited higher concentrations of BPA and E2 compared to juvenile individuals (less than 3 months old), with specific values of 6.40 ± 0.52 cm and 2.29 ±0.65 cm in shell length, respectively. The bio-concentration factor for BPA was determined to be 1650 for adult mussels and 263 for juveniles, suggesting significant accumulation potential from the surrounding environment and reinforcing the positive correlation between age and concentration of BPA in the organism. Industrial and domestic wastewater are major contributors to BPA contamination, while E2 levels are linked to domestic waste runoff, particularly in densely populated areas. These findings raise concerns about the potential health risks associated with consuming green mussels from contaminated zones for humans, as BPA and E2 are known endocrine disruptors and have been found to influence multiple endocrine related pathways. It is crucial to establish monitoring to track contamination levels and inform aquaculture safety practices. Moreover, the bioaccumulation of BPA and E2 can have significant impacts on the health of green mussels. The contamination can affect the overall health of mussel populations and the ecosystems they inhabit. In addition, the bioaccumulation of EDCs in general can lead to altered reproductive function in mussels and potentially impact their growth and survival rates. This will not only affect biodiversity and the ecosystem, but even the Thai economy, as aquaculture is a major part of it. More research must be conducted on whether the high levels of E2 in mussels result from environmental accumulation or de novo synthesis, as seen in some other mollusks, as well as on the general impact it has on green mussels and associated organisms. (Ocharoen et al., 2018)

Another study investigated the effects of Bisphenol A on the expression of CYP1A Transcripts in Juvenile False Clown Anemonefish. The study showed that BPA is present in significant concentration in the Gulf of Thailand - for instance, in 37.13 ng/L on Wonapaha Beach, Chon Buri. BPA exposure has been shown to induce vitellogenin synthesis in fish, causing reproductive issues like reduced sperm quality and delayed ovulation. It is also acutely toxic to aquatic organisms at concentrations as low as 100 µg/L. To investigate this, the study utilized juvenile false clown anemonefish to assess the effects of low-dose BPA exposure on gene expression, specifically the cytochrome P450 1A gene (CYP1A), which serves as a biomarker for environmental pollutants. Specifically, fish were exposed to BPA at concentrations of 0, 50, and 100 ng/L for varying durations. The liver was identified as the primary site for BPA accumulation, significantly higher than in muscle tissue. Following BPA exposure, CYP1A gene expression increased in a dose- and time-dependent manner, with notable increases observed after 12 and 24 hours of exposure to 100 ng/L and 50 ng/L respectively. These results indicate that CYP1A can effectively serve as a biomarker for monitoring BPA exposure in marine fish, highlighting its utility in assessing environmental health.("Effects of Bisphenol a on the Expression of CYP1A Transcripts in Juvenile False Clown Anemonefish (Amphiprion Ocellaris)," n.d.)

Tributyltin (TBT)

Tributyltin (TBT) is an organotin compound. TBTs are the main active ingredients in certain biocides used to control a broad spectrum of organisms, and are also used in wood preservation, marine paints, and textiles and industrial water systems, as antifouling pesticides and antifungal agents respectively. They are considered moderately to highly persistent organic pollutants, and are especially hazardous to marine ecosystems. (PubChem, n.d-a.)

Organotin compounds produce neurotoxic and immunotoxic effects. They might directly activate glial cells contributing to neuronal cell degeneration by local release of pro-inflammatory cytokines, tumor necrosis factor-alpha, and/or interleukins. Current research also points out to organotin compounds possibly inducing apoptosis by direct action on neuronal cells. Furthermore, these compounds stimulate the neuronal release of and/or decrease of neuronal cell uptake of neurotransmitters in brain tissue, which may contribute to or result in neuronal cell loss. The immunotoxic effects of organotins include thymic atrophy caused by the suppression of proliferation of immature thymocytes and apoptosis of mature thymocytes. It is believed that these compounds exert these effects by suppressing DNA and protein synthesis, including the expression of genes involved in apoptosis, and disrupting the regulation of intracellular calcium levels, which results in the uncontrolled production of reactive oxygen species, release of cytochrome c to the cytosol, and the proteolytic and nucleolytic cascade of apoptosis. Moreover, the suppression of proliferation of immature thymocytes further results in the suppression of T-cell-mediated immune responses. (PubChem, n.d.-b)

Organotins are also endocrine disrupting chemicals, and are believed to be obesogens. Inorganic tin also triggers eryptosis, contributing to tin-induced anemia. Given the highly damaging impacts of organotin on human health and it's status as a moderately to highly persistent organic pollutant in our oceans, it is not far-fetched to be worrisome of the impact of TBT as an endocrine disruptor on marine wildlife.

A significant impact of TBT as an endocrine disrupting chemical is its ability to cause imposex in certain marine organisms, a kind of irreversible pseudohermaphroditism in which the females develop male features in the reproductive system such as a penis and vas deferens that provokes sterility. It can also cause females to die prematurely. These effects increase the risk that a species may go extinct. (Espinosa & Bazairi, 2023b)

This phenomenon has been documented in the Gulf of Thailand. In 2006, Imposex in neogastropods was used to determine the relative TBT distribution in the Gulf of Thailand, and imposex was detected in every area of the sample studied. The same study also reported the overall frequency of imposex in the Gulf of Thailand significantly increased from 1996 to 2006, suggesting the concentration of TBT in that environment also increased. Given the continuous increase in anthropogenic and industrial activities in the region, this trend can be projected in the years after 2006 as well. (Swennen et al., 2009)

Another study investigated the phenomenon of imposex in sublittoral and littoral gastropods from the Gulf of Thailand and the Strait of Malacca, identifying a positive correlation between the occurrence of imposex and shipping activities in the region. TBT concentrations were also measured in the tissues of gastropods, revealing that higher concentrations were associated with areas of heavy maritime traffic. This was linked to reproductive failure and population declines in female gastropods, which can be detrimental for the entire population. Although this study was conducted in 1997, it still remains highly relevant. The Gulf of Thailand, as discussed earlier, remains an important maritime trading hub and a sea lane of connection between the West and East. There are still increased shipping activities in the region, which could mean that the area is also heavily polluted with TBT. Extensive research and further studies must be conducted not only to assess the long-term impacts of TBT as an endocrine disrupting chemical and its impacts on marine ecosystems, but also to explore alternative antifouling strategies and manage chemical pollutants in marine environments to protect biodiversity and maintain ecosystem health. (Swennen et al., 1997)

A study conducted on imposex in *Thais gradata* as a Biomarker for TBT pollution has also provided valuable insights on the ubiquity of this chemical in the natural environment. *Thais gradata* samples were collected from six locations along the southern shores of Peninsular Malaysia and analyzed for imposex incidence and butyltin and phenyltins concentrations in tissues. Levels of butyltins, including TBT, were found to be higher than levels reported a year earlier, while the phenyltins were lower. The study classified the morphological expressions of imposex in the species into seven stages by observing the development of vas deferens sequence and penis bulk. Locations with high imposex levels tended to have high BT levels in the snail tissue samples, although correlation analysis did not show a significant relationship between the two parameters. Still, the non-significant correlation between shell height and organotin compounds, along with no significant differences between BT levels in female and lower imposex stage samples, suggests recent TBT contamination. The study provides direct evidence of endocrine disruption caused by TBT. (Mohamat-Yusuff et al., 2010)

Phthalate Esters

Phthalate esters are a class of synthetic, industrial chemical compounds containing a phenyl ring with two attached and extended acetate groups. They are widely used in the manufacture of products for commercial, consumer, and or military use, such as munitions, seals, adhesives, and flexible plastics. The largest use for these chemicals is to plasticize PVC vinyl resins, which makes it flexible. They may also be found in products such as toothbrushes, automobile parts, tools, toys, and food packaging. Recently, there have been increased reports of the potential toxicity and emerging evidence of adverse impacts on reproductive system development of phthalate esters, raising concerns about the chemical's endocrine disrupting abilities. (*The Basics – Chemical and Material Risk Management Program*, n.d.)

Specifically, reproductive effects of phthalate esters are well characterized in adult animals, with gonadal injury observed after high dose exposure. Recent transgeneration studies indicate that the reproductive system of developing animals are particularly vulnerable to certain phthalates(Martino-Andrade & Chahoud, 2009). Concerns that phthalates might also be oestrogenic have arisen from observations that the diesters inhibited the binding of 17β-estradiol to isolate estrogen receptors and stimulated the expression of cellular estrogen-sensitive endpoints like gene expression and mitosis in vitro. (Moore, 2000)

Phthalate esters are increasingly recognized as prevalent contaminants in the Gulf of Thailand, particularly in aquatic environments, and pose a significant threat to aquatic life. They may also have implications for local communities reliant on contaminated water sources and fishing.

A study investigating the occurrence, Ecological and Health Risk Assessment of Phthalate Esters in Surface Water of U-Tapao Canal, Southern, Thailand, focused on three specific PAEs detected in water samples: di-n-butyl phthalate (DBP), di (2-Ethylhexyl) phthalate (DEHP), and diisononyl phthalate (DiNP). The total concentrations of PAEs ranged from 1.44 to 12.08 μg/L, with an average of 4.76 μg/L. These levels significantly exceed the USEPA recommended limit of 3 μg/L for protecting aquatic life. Using the risk quotient method (RQ), DEHP and DiNP were found to pose a high ecological risk to algae and crustaceans, while DBP presented a medium risk to various aquatic species. PAEs are hence endocrine disrupting chemicals that can adversely impact the reproduction and development of sensitive aquatic organisms in the U-Tapao canal and the Gulf of Thailand. The contamination is attributed to untreated and semi-treated wastewater from industrial and municipal sources, agricultural runoff, and atmospheric deposition. These sources likely contribute to the presence of PAEs throughout the canal system and into the Gulf of Thailand. Understanding the occurrence and ecological risks of PAEs as EDCs is a critical first step in mitigating their impacts on aquatic life in the Gulf of Thailand. Furthermore, establishing regulations for PAEs and other EDCs, which is currently lacking, is crucial to safeguarding aquatic ecosystems in the Gulf of Thailand. (Kingsley & Witthayawirasak, 2020)

A study in 2019 investigated the occurrence of phthalate esters in seawater and sediment along the eastern coast of Thailand, particularly in the area of Pradu Bay near the Map Ta Phut industrial estate. Among the six phthalates studied, dibutyl phthalate (DBP) and diethylhexyl phthalate (DEHP) were considered the predominant PAEs present. In December 2014, the concentrations of DBP and DEHP in Pradu Bay were 0.23-0.77μg L^{-1} for DBP and 0.31–0.91 μg L^{-1} for DEHP, and non-detected (ND)–0.80 μg g^{-1} for DBP and ND–1.65 μg g^{-1} for DEHP in 11 out of 20 samples in seawater and sediment respectively. A comparison with EU standard concentration limits confirmed that phthalate levels in this area were acceptable. However, given that PAEs are a known endocrine disruptor, continuous monitoring of phthalate congeners was recommended to detect possible increases in their concentrations.

These chemicals can induce cancer, malformations, and liver and kidney injury in animals. Specifically, populations of fish and invertebrates are affected by exposure to low molecular weight phthalates like DBP, but not by high molecular weight phthalates. (Malem et al., 2019)

Metalloestrogens

Metalloestrogens are metal ions that exhibit estrogen-like activity that can disrupt normal endocrine function. These ions can bind to estrogen receptors, leading to altered gene expression and hormonal signaling pathways, which may result in reproductive and developmental issues. Exposure to metalloestrogens has been linked to various concerns, including infertility, developmental abnormalities, and increased risk of certain cancers, especially those that are hormone-dependent, like breast and prostate cancer. Common metalloestrogens include lead, cadmium, and mercury, and these metals have been studied in detail, providing a plethora of evidence of the potent endocrine disruptors these metals can be. Moreover, these substances can persist in the environment, leading to bioaccumulation in organisms and the successive disruption in ecosystems.

Recent studies have shown that heavy metal contamination is pervasive in Thailand. Sediment cores from the Songkhla Lake, which is connected to the Gulf of Thailand, has shown increased concentrations of trace metal like lead, mercury, arsenic, zinc, and nickel since the 1980s due to urban and industrial pollution, strongly alluding to the potential presence of metalloestrogens in the Gulf. (Dong et al., 2021)

Similarly, a study analyzing heavy metals in fish, crab and shrimp from the Gulf found that mercury levels in some fish species like Gymnothorax and Terapon exceeded safe limits for human consumption. This suggests that there could be adverse effects on the organisms, especially as mercury is a known metalloestrogen that has been shown to bioaccumulate in marine organisms.(Prabakaran et al., 2023)

Metalloestrogens have been found to significantly impact seagrass beds in the Gulf of Thailand through various mechanisms related to pollution and habitat degradation. Heavy metals can accumulate in sediments and seagrass tissues, leading to physiological stress. For example, excess copper has been shown to cause chlorosis, inhibit root growth, and damage cell membranes in plants, which can ultimately lead to reduced growth and survival of seagrass.(Vo et al., 2020) Additionally, eutrophication can be exacerbated by the effects of heavy metal pollution, as the increased nutrient levels can lead to algal blooms which reduce light penetration and hinder photosynthesis in seagrass beds. The presence of heavy metals also causes a degradation in water quality, making it less suitable for seagrass growth. This is extremely concerning, as seagrasses provide essential ecosystem services, such as habitat for marine life and stabilization of sediments.

The stress from heavy metal induced habitat degradation can lead to long-term declines in seagrass populations. This poses a massive risk for the small, remaining Dugong population in Thailand. In the past, dugongs were commonly seen along both coasts of Thailand, but now they are mainly reported in the Andaman Sea, where it is estimated there are 200 dugongs, and the Gulf of Thailand. The largest dugong population is in a marine protected area around Koh Libong and Koh Muk, in Trang Province. Plastic also poses a risk for the dugong population in the area, with up to eight dugongs dying each year due to incidental entanglement in fishing nets. (*Thailand - Dugong &Amp; Seagrass Hub*, 2023b)

As of now, there is weak evidence suggesting ecotoxicological impacts due to metalloestrogens and organochlorines on Sirenians (The Dugong is one of the four living species in the order Sirenia), and the general findings in the late 20th century and early 21st century has been that very low concentrations of endocrine disrupting chemicals persist in Sirenians. However, updated research is required to provide a better perspective on the current concentration of EDCs in Sirenians, especially in Dugongs. Currently, undoubtedly the most pervasive threat faced by dugongs is habitat degradation, and it is imperative that legislation is established to eliminate or reduce industrial runoff and anthropogenic activities in the area, and conservation measures must be taken to prevent this species from facing extinction.

Conclusions

The presence of endocrine-disrupting chemicals in the Gulf of Thailand is most certainly a critical environmental issue in that region. However, it also represents a more significant, far-reaching issue that has global implications for both marine systems and human health. Currently, all existing evidence points strongly towards the fact that common chemicals used in production and other anthropogenic activities are significant EDCs that have detrimental impacts on all organisms. This literature review has highlighted several studies and projects focusing on EDCs in the Gulf of Thailand. Despite this considerable amount of data and ongoing research, several knowledge gaps remain. The specific chemical and biological mechanisms by which these chemicals disrupt marine organisms and impact their surrounding environment need further exploration. Additionally, few studies have explored the long-term impacts on regional human populations that rely on seafood from contaminated areas. Reproductive, developmental, and hormonal disruptions in not only humans but also wildlife will require continued monitoring and targeted studies to assess these risks. Immediate action is required to fill the knowledge gaps regarding the long-term impacts of EDCs on marine life and human health in the Gulf of Thailand. It is recommended that more research is conducted to quantify the level of EDCs present in the Gulf, as well as the impact of certain EDCs on general wildlife. Additionally, more research is also required on the impact of EDCs on vulnerable organisms, such as the dugong, to better inform conservation efforts in the region, and protect Thailand's impressive biodiversity.

References

1. Dick Vethaak, Juliette Legler (2013) Endocrine Disruption in Wildlife: Background, Effects, and Implications https://doi.org/10.1002/9781118355961.ch2
2. *Thailand's petrochemical industry*. (2024, September 24). AIChE. https://www.aiche.org/resources/publications/cep/2019/may/thailands-petrochemical-industry
3. *What are microplastics?* (n.d.). https://oceanservice.noaa.gov/facts/microplastics.html
4. SEA circular Project. (2023, August 8). *Thailand - SEA circular Project*. SEA Circular Project. https://www.sea-circular.org/country/thailand/
5. Pradit, S., Noppradit, P., Sornplang, K., Jitkaew, P., Jiwarungrueangkul, T., & Muenhor, D. (2024). Occurrence and abundance of microplastics in surface water of Songkhla Lagoon. *PeerJ*, *12*, e17822. https://doi.org/10.7717/peerj.17822
6. Chaisanguansuk, P., Phantuwongraj, S., Jirapinyakul, A., & Assawincharoenkij, T. (2023). Preliminary study on microplastic abundance in mangrove sediment cores at Mae Klong River, upper Gulf of Thailand. *Frontiers in Environmental Science*, *11*. https://doi.org/10.3389/fenvs.2023.1134988
7. Rahman, M. N., Shozib, S. H., Akter, M. Y., Islam, A. R. M. T., Islam, M. S., Sohel, M. S., Kamaraj, C., Rakib, M. R. J., Idris, A. M., Sarker, A., & Malafaia, G. (2023). Microplastic as an invisible threat to the coral reefs: Sources, toxicity mechanisms, policy intervention, and the way forward. *Journal of Hazardous Materials*, *454*, 131522. https://doi.org/10.1016/j.jhazmat.2023.131522
8. Srisiri, S., Haetrakul, T., Dunbar, S. G., & Chansue, N. (2024). Microplastic contamination in edible marine fishes from the upper Gulf of Thailand. *Marine Pollution Bulletin*, *198*, 115785. https://doi.org/10.1016/j.marpolbul.2023.115785
9. Srisiri, S., Chulalongkorn University, & Chula Digital Collections. (2020). Surveillance and histopathological study of microplastics in marine fish from the gulf of Thailand. In N. Chansue, R. Thanawongnuwech, S. Pakpinyo, N. Pirarat, J. Tangtrongpiros, Amonrat Sermwatanakul, S. Nuanualsuwan, Thailand Science Research and Innovation (TSRI), Research Cluster on Microplastics and Plastic Wastes, Chulalongkorn University, Environmental Research Institute, Chulalongkorn University, D.

Palić, & S. Wassanadumrongdee (Eds.), Chulalongkorn University Theses and Dissertations (Chula ETD). https://digital.car.chula.ac.th/chulaetd/419
10. Pradit, S., Noppradit, P., Jitkaew, P., Sengloyluan, K., Yucharoen, M., Suwanno, P., Tanrattanakul, V., Sornplang, K., & Nitiratsuwan, T. (2023). Microplastic Accumulation in Catfish and Its Effects on Fish Eggs from Songkhla Lagoon, Thailand. Journal of Marine Science and Engineering, 11(4), 723. https://doi.org/10.3390/jmse11040723
11. Yasaka, S., Pitaksanurat, S., Laohasiriwong, W., Neeratanaphan, L., Jungoth, R., Donprajum, T., & Taweetanawanit, P. (2022). Bioaccumulation of microplastics in fish and snails in the Nam Pong River, Khon Kaen, Thailand. EnvironmentAsia, 15(1), 101-111 https://doi.org/10.14456/ea.2022.8
12. Pradit, S., Noppradit, P., Goh, B., Sornplang, K., Ong, M., & Towatana, P. (2022). OCCURRENCE OF MICROPLASTICS AND TRACE METALS IN FISH AND SHRIMP FROM SONGKHLA LAKE, THAILAND DURING THE COVID-19 PANDEMIC. Applied Ecology and Environmental Research, 19(2), 1085–1106. https://doi.org/10.15666/aeer/1902_10851106
13. Hewawasam, U. E. I. (2021). Extraction and identification of microplastics in green mussels in Thailand
14. Rubin, B. S. (n.d.). Bisphenol A: An endocrine disruptor with widespread exposure and multiple effects. The Journal of Steroid Biochemistry and Molecular Biology, 127(1–2), 27–34. https://doi.org/10.1016/j.jsbmb.2011.05.002
15. Ocharoen, Y., Boonphakdee, C., Boonphakdee, T., Shinn, A. P., & Moonmangmee, S. (2018). High levels of the endocrine disruptors bisphenol-A and 17β-estradiol detected in populations of green mussel, Perna viridis, cultured in the Gulf of Thailand. Aquaculture, 497, 348–356. https://doi.org/10.1016/j.aquaculture.2018.07.057
16. Effects of Bisphenol A on the Expression of CYP1A Transcripts in Juvenile False Clown Anemonefish (Amphiprion ocellaris). (n.d.). Genomics and Genetics. https://doi.org/10.14456/gag.2020.8
17. PubChem. (n.d.-a). Tributyl tin. PubChem. https://pubchem.ncbi.nlm.nih.gov/compound/Tributyl-tin
18. PubChem. (n.d.-b). Tributyl tin. PubChem. https://pubchem.ncbi.nlm.nih.gov/compound/Tributyl-tin#section=Toxicity
19. Espinosa, F., & Bazairi, H. (2023b). Impacts, evolution, and changes of pressure on marine ecosystems in recent times. Toward new emerging and unforeseen impacts within a changing world. In Elsevier eBooks (pp. 1–16). https://doi.org/10.1016/b978-0-323-85613-3.00004-9
20. Swennen, C., Sampantarak, U., & Ruttanadakul, N. (2009). TBT-pollution in the Gulf of Thailand: A re-inspection of imposex incidence after 10 years. Marine Pollution Bulletin, 58(4), 526–532. https://doi.org/10.1016/j.marpolbul.2008.11.028
21. Swennen, C., Ruttanadakul, N., Ardseungnern, S., Singh, H. R., Mensink, B. P., & Hallers-Tjabbes, C. C. T. (1997). Imposex in Sublittoral and Littoral Gastropods from the Gulf of Thailand and Strait of Malacca in Relation to Shipping. Environmental Technology, 18(12), 1245–1254. https://doi.org/10.1080/09593331808616646
22. Mohamat-Yusuff, F., Zulkifli, S. Z., Ismail, A., Harino, H., Yusoff, M. K., & Arai, T. (2010). Imposex in Thais gradata as a Biomarker for TBT Contamination on the Southern Coast of Peninsular Malaysia. Water Air & Soil Pollution, 211(1–4), 443–457. https://doi.org/10.1007/s11270-009-0314-3
23. The Basics – Chemical and Material Risk Management Program. (n.d.). https://www.denix.osd.mil/cmrmp/ecmr/phthalate/basics/
24. Martino-Andrade, A. J., & Chahoud, I. (2009). Reproductive toxicity of phthalate esters. Molecular Nutrition & Food Research, 54(1), 148–157. https://doi.org/10.1002/mnfr.200800312
25. Moore, N. P. (2000). The oestrogenic potential of the phthalate esters. Reproductive Toxicology, 14(3), 183–192. https://doi.org/10.1016/s0890-6238(00)00068-x

26. Kingsley, O., & Witthayawirasak, B. (2020). Occurrence, ecological and health risk assessment of phthalate esters in surface water of U-Tapao Canal, Southern, Thailand. Toxics, 8(3), 58. https://doi.org/10.3390/toxics8030058
27. Malem, F., Soonthondecha, P., Khawmodjod, P., Chunhakorn, V., Whitlow, H. J., & Chienthavorn, O. (2019). Occurrence of phthalate esters in the eastern coast of Thailand. Environmental Monitoring and Assessment, 191(10). https://doi.org/10.1007/s10661-019-7785-5
28. Dong, K., Qiao, S., Wu, B., Shi, X., Chen, Y., Shan, X., Liu, S., Kornkanitnan, N., & Khokiattiwong, S. (2021). Sedimentary history of trace metals over the past Half-Century in Songkhla Lake, western coast of the Gulf of Thailand: Anthropogenic impacts and contamination assessment. Frontiers in Earth Science, 9. https://doi.org/10.3389/feart.2021.767899
29. Prabakaran, K., Sompongchaiyakul, P., Bureekul, S., Wang, X., & Charoenpong, C. (2023). Heavy metal bioaccumulation and risk assessment in fishery resources from the Gulf of Thailand. Marine Pollution Bulletin, 198, 115864. https://doi.org/10.1016/j.marpolbul.2023.115864
30. Vo, T., Lau, K., Liao, L. M., & Nguyen, X. (2020). Satellite image analysis reveals changes in seagrass beds at Van Phong Bay, Vietnam during the last 30 years. Aquatic Living Resources, 33, 4. https://doi.org/10.1051/alr/2020005
31. Thailand - Dugong & Seagrass Hub. (2023b, January 16). Dugong & Seagrass Hub. https://www.dugongseagrass.org/where-we-work/thailand/