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Cover Page Footnote
Isabelle Ng was born and raised in Hong Kong. She grew up surrounded by environmental issues in her hometown such as air pollution, overfishing, and overflowing landfills. The issue of shark finning, in particular, caught her attention and at ten years old, she decided to dedicate her life's work to protecting marine life. Isabelle graduated from Pitzer College in 2017 with a degree in Organismal Biology and Environmental Policy. This coming August, she will be working in Singapore for Ecofieldtrips, a company which organizes biology and conservation focused trips around Southeast Asia for primary up to high school level students. She will be leading such trips with the intent to inspire students about the importance of our environment. Isabelle hopes to further her education by pursuing a master's degree in Marine Biology.

The impacts of logging and palm oil on aquatic ecosystems and freshwater sources in Southeast Asia

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Abstract: The process of deforestation has large environmental implications on terrestrial as well as aquatic habitats. Palm oil plantations lead to sedimentation and agricultural runoff into streams and rivers. Such high nutrient inputs could lead to eutrophication, bioaccumulation, and toxic blooms, which could lead to changes in aquatic ecosystems as well as drinking water quality for surrounding communities. Pollutants from streams and rivers are furthermore, channeled down into estuarine and coastal marine ecosystems, thus negatively impacting those areas as well. One possible way to reduce the amount of runoff is by treating the waste produced by palm oil mills as well as converting the waste into biogas. This could make the mill self-sustaining or allow it to produce surplus energy for additional economic gain.

Oil palm is Malaysia’s second largest export commodity and oil palm plantations make up 56 percent of the country’s forestland (Donald, 2004, 29). With large export commodities such as palm oil, Malaysia is rapidly undergoing development and industrialization, but of course, all of this comes with a cost.

Creating palm oil plantations means that large areas of forest must be deforested prior. The impacts of deforestation are huge – it leads to habitat loss for endemic organisms in the region, the displacement of those who live in the forest as well as cause increases in atmospheric pollution. For example, in Sarawak, the air pollution index consistently surpasses 500 which is the level at which inhabitants should evacuate (Donald, 2004, 30). Deforestation can also lead to sedimentation in rivers and streams, which then impact drinking water quality as well as the health of these aquatic ecosystems.

In addition to the impacts from deforestation, palm oil also requires large amounts of agrochemicals such as fertilizers, pesticides, and herbicides (Donald, 2004, p.29). These agrochemicals can be leached into soils or runoff into aquatic ecosystems. Agrochemicals can be high in nutrient concentration and pollutants, thus negatively impacting aquatic species as well as drinking water sources. Palm oil plantations also

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produce waste product called Palm Oil Mill Effluent (POME). POME has high nutrient concentrations and pollutants, so when released into a body of water, it will lead to algal blooms and subsequent loss of biologically active oxygen in the water (Donald, 2004, 30). A lack of oxygen in water bodies will consequently mean a loss of all life in those aquatic ecosystems.

There appears to be a heavy body of literature assessing the impacts of palm oil plantations on our terrestrial ecosystems. For this reason, I seek to uncover the impacts of palm oil production on the health of aquatic ecosystems as well as drinking water resources. Additionally, I will be discussing steps that the Malaysian government has taken to reduce palm oil effluent from plantations around the country.

Palm oil agrochemicals and effluent

Agricultural activities are the main source of water pollution by the discharge of high nutrient compounds such as ammonia. Eutrophication occurs when a large amount of nutrients - usually nitrogen and phosphorus compounds - are released into a body of water, thus leading to increased primary productivity (Todd et al., 2015, p.1067). Eutrophication can occur naturally through upwelling or through human activities such as agriculture.

In monoculture plantations, pesticides are heavily applied. Pesticides are excessively applied because large amount of it will be released into the environment (Islam & Tanaka, 2004). Excess pesticides will either build up in soils, runoff from the soil into surface waters, leach into groundwater, or evaporate into the atmosphere (Smith, 1999, 180). Asian countries with high agricultural yield discharge a significant amount to aquatic pollution (Islam & Tanaka, 2004). Pesticides have devastating impacts to all aquatic ecosystems via bioaccumulation and Biomagnification of chemicals in marine organisms (Islam & Tanaka, 2004). Bioconcentration occurs when an organism like suspension feeding plankton for example, absorbs chemical compounds in agricultural wastes (Islam & Tanaka, 2004). Biomagnification occurs when higher trophic level species consume organisms that have already bioaccumulated chemicals from pesticides. These chemicals will biomagnifiy throughout the food web and could potentially impact humans if these marine organisms are consumed for food.

Palm oil effluent has similar, if not more intense effects on aquatic ecosystems. Effluent from palm oil can be dumped into the nearest waterways from the production plant. POME contains high nutrient concentrations and when released into water, will lead to eutrophication. POME has been found to deplete oxygen in water bodies about 100 times more than domestic sewage (Donald, 2004). This high-powered depletion of oxygen puts aquatic organisms at risk of extinction. Fertilizer runoff and POME will pollute water bodies and impact all trophic levels, thereby altering the aquatic community and eventually ecosystem functioning (Todd et al., 2015, 1063). About 70% of Southeast Asia inhabitants live by the coast and are impacted by such water pollution from deforestation and agriculture (Todd et al., 2015, 1063). The world's marine biodiversity is also in danger, as Southeast Asia contains about 34 percent of the world's reefs, about a third of the world's mangroves, and the global biodiversity triangle formed by Peninsular Malaysia, the Philippines, and New Guinea (Todd et al., 2015). This triangle is a biodiversity hotspot, where majority of tropical marine

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groups have their highest abundances of species (Todd et al., 2015). While Southeast Asia is the host of such diverse marine life, over 80% of its reefs are already at risk (Todd et al., 2015). There is clearly much urgency to reduce the amount of pollution that enters aquatic ecosystems.

Impacts on lakes and reservoirs

Eutrophication in lakes and reservoirs can lead to a number of issues. An influx of fertilizer runoff or palm oil effluent into lakes and reservoirs means that there is an abundance of nutrients for freshwater phytoplankton to thrive. As such, it is typical to see a substantial increase in phytoplankton biomass. We might also observe a shift in phytoplankton species composition to species that are toxic or inedible by their predators (Smith, 1999, p.182). These are called toxic blooms, which will consequently take over and alter freshwater communities (Smith, 1999, 182). Toxic blooms may also alter the taste and odor of water supplies, causing potential health risks to those that rely on these water resources for their livelihoods. Increased abundances of phytoplankton also means reduced water clarity, which reduces light penetrability for other photosynthetic organisms such as vascular plants (Smith, 1999, 182). These impacts could also alter vascular plant species composition and their primary consumers.

Eutrophication can also lead to higher pH levels and lower dissolved oxygen levels in the water column, thus impacting the survival rates of the organisms living there (Smith, 1999, p.182). Such conditions may cause extinctions of endemic species, leaving only those who can survive under such extreme conditions. These species are often undesirable and/or nonnative (Smith, 1999, 182).

Impacts on estuarine and coastal marine ecosystems

The pollutants from streams and rivers are channeled down into estuarine and coastal marine ecosystems, thus negatively impacting those areas as well (Smith, 1999, p.186). Eutrophication can impact these ways in numerous ways. It marine environments, it usually leads to phytoplankton blooms (Smith, 1999, p.186). Some of these phytoplankton species are toxic or poisonous and lead to Harmful Algal Blooms (HABs). These phytoplankton blooms are worse in marine than freshwater ecosystems since there is a greater diversity of toxic phytoplankton that can significantly impact species composition and abundances in the community (Smith, 1999, 186). Toxic dinoflagellates may also cause paralytic shellfish poisoning. Because many shellfish are suspension feeders, they easily absorb these toxins, and such toxins can travel up the food chain through Biomagnification (Todd et al., 2015, 1068). Such effects may also mean massive losses in commercial shellfish fisheries (Smith, 1999, 186). Shifts in abundances of certain marine organisms could also impact fish stocks.

High nutrient concentrations have also been found to deleteriously impact marine disease. Field research by Bruno et al. (2013) showed that nutrient enrichment exacerbates two Caribbean coral diseases: aspergillosis of *Gorgonia ventalina* and yellow band disease of two reef-building corals *M. annularis* and *M. franksii*. This may be because high nutrient concentrations may improve pathogen fitness and severity (Bruno et al., 2013). This could have serious implications reef communities, as corals are foundation species in which many species rely on for food, habitat and larval settlement.

Non-toxic phytoplankton blooms can also negatively impact marine ecosystems. Phytoplankton blooms lead to higher turbidity, which decreases the ability for light to penetrate (Todd et al., 2015, 1068). Less light means lower levels of photosynthesis and thereby threatening the survival of photosynthesizing organisms. For example, corals may expel their symbiotic zooxanthellae, thus leading to bleaching and subsequent impacts to their survival. Additionally, corals are adapted to live in low nutrient waters, meaning that nutrient discharge into marine ecosystems could lead to disease, reduced fertilization and settlement rates in coral communities (Todd et al., 2015, p.1069). Due to high nutrient concentrations, coral biodiversity in parts of Indonesia have declined by up to 60% (Todd et al. 2015, 1068).

Sea grasses are also impaired by high nutrient discharge. Macroalgal blooms caused by high nutrient waters lead to greater competition between macroalgae and sea grass for nutrients and light. A loss of sea grass would significantly shift trophic structure in sea grass bed habitats by increasing detritivores abundances and decreasing herbivore and macroinvertebrate diversity (Todd et al., 2015, p.1069).

Phytoplankton blooms may also lead to hypoxic or anoxic conditions. When phytoplankton abundance is much higher than the abundance of suspension feeders, a large amount of phytoplankton will die and settle on the seabed. Bacterial decomposers will consume the dead matter on the seabed and cause oxygen to be depleted. This will create an anoxic or hypoxic bottom layer called a dead zone, which can lead to mortality, reduced growth rates or changes to distribution and behaviors of fishes (Todd et al., 2015, p.1068).

Sedimentation's influence on aquatic ecosystems

High sediment load in water bodies can be caused natural processes or by land use changes through logging or clearing for agriculture (Todd et al., 2015, 1064). High sediment loads can impact physically change marine habitats by smothering coral or sea grass beds (Todd et al., 2015, 1066). This subsequently reduces the habitat available for larval settlement as well as the ability for fish to spawn on gravel beds (Todd et al., 2015, 1066). High sediment loads also leads to high turbidity, which limits the growth of algae and rooted plants. Sediment can also carry organic chemicals into water bodies (Islam & Tanaka, 2004). Such organic chemicals may be toxic and bioaccumulate in marine organisms through ingestion or by consumption of smaller trophic level species. Sedimentation is currently one of the largest threats to tropical reefs around the world (Islam & Tanaka, 2004).

The effects of smothering vary across species and the scale of smothering also dependent on sedimentation rates and particle size (Todd et al., 2015, 1066). Corals for example, will have higher relative respiration rates due to their increased use of energy to clear debris. Higher respiration rates means that there is lowered net photosynthesis during the day. Smothering also reduces the ability for coral larvae to settle, thus deleteriously impacting the abundance and diversity of coral species. It is fair to assume that smothering would inhibit the settlement of other larval species as

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well. In more extreme cases, smothering can lead to mortality by complete burial (Todd et al., 2015, 1066).

Sedimentation can significantly impact light penetration in marine ecosystems. By limiting the amount of light that can pass through, high sediment loads are limiting photosynthesis and thus the growth rates of photosynthesizing organisms. Additionally, photosynthesis and calcification has been found to be highly associated among zooxanthellate scleractinian corals (Todd et al., 2015, 1066). Calcification occurs when corals produce calcium carbonate – which is how reefs are formed. Thus, it is concerning that calcification rates are found to be about three times lower in the dark than light (Todd et al., 2015, 1066). Heavy sediment input has been an issue in Singapore for decades. Eight m of visibility underwater has been lost over the last 55 years and this has led to coral dead zones below 6-8m across the coast (Todd et al., 2015, 1066).

Sea grass beds are by typically by the coast, which makes them adapted to live in sediment (Todd et al., 2015, 1066). However, sea grasses are sensitive to changes in sediment inputs. Freeman et al. (2008) found that terrestrial sedimentation from deforested areas in Sabah, Malaysia has led to reduced water clarity and light penetrability, thus causing sea grass decline. They also found that the logging had been consistently causing sediment input into the coast for the last 10 years. Smothering via sedimentation has led to about 50 percent of mortality in sea grasses (Todd et al., 2015, 1066). Sea grasses are foundation species, because they provide habitat for organisms to reside and are even the host of epiphytes. As such, when sea grass beds are buried, there is also high mortality for a vast majority of the ecosystem. More subtle effects of sedimentation on sea grasses include decreases in biomass, nutrients, and chlorophyll content.

Mangrove ecosystems are also deleteriously impacted by sedimentation. Mangroves cope with the low oxygen soft sediments in which they grow on by having aerial roots. As such if their aerial roots are buried via sedimentations, they will face mortality. This is harmful to all marine ecosystems because mangroves serve as breeding and nursery areas for shrimps, crabs and marine fish while also providing shelter and food for other terrestrial species like monkeys and migratory birds (Jusoff, 2013). If mangrove survival is impaired by sedimentation, so will the survival of the species that rely on mangroves. Moreover, mangrove forests themselves are a form of coastline protection against strong waves, winds, and natural disasters such as tsunamis and storms (Jusoff, 2013). Mangrove forests also provide a variety of ecosystem services, by regulating erosion and flooding, protecting rivers against saltwater intrusion, by recycling nutrients and filtering toxics (Jusoff, 2013). They provide a vast amount of resources such as food, timber and medicine for coastal communities (Jusoff, 2013). In Sarawak, mangrove forests support marine fisheries up to US$21.1 million dollars, timber products up to $123,217 as well as tourism US $3.7 million (Bennett & Reynolds, 1992). Conservation management is vital, as an the endangerment of mangroves would translate into losses in coastal protection, ecosystem function, species diversity and the local economy.

Reducing Oil-palm’s impact

One way in which we can reduce the impacts of palm oil on our aquatic ecosystems is by treating the waste produced by palm oil mills. Palm oil mills consume large amounts of water and energy for production while also generating large quantities of wastewater and air pollution (Abdullah & Sulaiman, 2013). The wastewater palm oil plantations produce is called palm oil effluent (POME). Such waste is extremely high in nutrient concentrations, and can deleteriously impact aquatic ecosystems as described previously. One way of reducing the impacts of POME on the surrounding environment is by creating biofuels from it. Biogas can be generated during POME digestion, and such energy recovery from these wastes can be used (Abdullah & Sulaiman, 2013). This biogas can be compressed and subsequently used to fuel electricity. A mill can potentially convert all its waste into biogas and produce enough energy to be a self-sustaining mill while also producing surplus electricity to the grid (Abdullah & Sulaiman, 2013). By maximizing energy recovery from palm oil mill wastes, we can decrease the environmental impacts while increasing economic gains.

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