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POLICY BRIEF

eDNA Detection to Help Combat Illegal Fishing and Modern Slavery

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KEY POINTS

- Innovations in DNA-based identification and traceability can now be implemented in Philippine fisheries, serving as solutions that can keep pace with the complex, fast-moving global seafood supply chain.
- Seafood fraud is prevalent in the fishing industry and can occur because of illegal fishing, some of which comes from vessels that utilize modern slavery.
- With global seafood demand projected to rise through 2030, the challenges of illegal fishing and modern slavery at sea become increasingly linked; challenges which can be reduced by the adoption of emerging eDNA-based tools by both exporting and importing nations, including the Philippines and the United States.

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1. eDNA metabarcoding

Environmental DNA (eDNA) is the collection of free DNA molecules that are left behind in an environment that can be used as a source to identify organisms that are or have recently been in a specific location (Pilliod et al. 2013; Ames et al. 2021). All living organisms shed eDNA in the form of skin, scales, metabolic waste, and others into their surrounding aquatic or terrestrial habitat. eDNA metabarcoding is a molecular genetics method that targets eDNA and, using next-generation sequencing technologies and universal genetic biomarkers, enables researchers to filter and sequence eDNA from an environmental water or air sample to identify the location's species composition (Kelly et al. 2014; Deiner et al. 2017; Johnson et al. 2021). The advantages of eDNA metabarcoding over well-vetted, traditional DNA barcoding (Ruppert et al. 2019) include the ability to detect multiple species from a single environmental sample and circumvent the need to trap or observe specimens from the habitat (Deiner et al. 2017).

In fisheries, eDNA metabarcoding can be used as a "forensics" tool, enabling rapid, non-lethal assessment of species composition for surveillance and monitoring (Willette et al. 2021a). It also has the potential to aid fisheries management for use in fish biomass assessments (Rourke et al. 2021), detect non-target or rare species as by-catch (Burgess et al. 2018), and track the impact of farmed fish escapes on wild fish stocks (Aguirre-Pabon et al. 2015). Traditional DNA barcoding has long been used in the surveillance of seafood in the Philippines and worldwide, most often and effectively in exposing seafood fraud in fish markets, grocers, and restaurants (Maralit et al. 2013; Willette et al. 2017; Luque and Donlan 2019; Willette et al. 2021b). However, traditional DNA barcoding's requirement to obtain individual tissue samples limits its application on fishing vessels and ports where landings of hundreds to thousands of fish may be moved and processed at a time. eDNA metabarcoding overcomes this limitation with the non-invasive screening of water, including wastewater, to identify multiple fish species simultaneously. Additionally, the declining cost of next-generation sequencing and

bioinformatics technologies (Willette et al. 2014), the continued growth of comprehensive and open-access genetic databases (Herbert et al. 2003; Janzen et al. 2005), and the construction of regional and national genomics facilities, including the Philippine Genomic Center, position eDNA metabarcoding as a potent tool to aid fisheries management needs (Bernatchez et al. 2017) and as versatile solution in addressing the concurrent national and international challenges of food security, illegal fishing and modern slavery.

2. What is the issue?

Roughly one-third of the world's fisheries are overfished, and 58% are fully exploited (Sutton and Siciliano 2016). As near-shore fish stocks decline, fishing vessels are pushed farther out to sea, where regulation is more difficult to enforce. The utilization of modern slavery on these vessels cuts labor costs and increases profits. Modern slavery is the exploiting and imprisoning of individuals through coercive practices, such as debt bondage. While modern slavery on fishing vessels occurs across the globe, it is most prominent in Southeast Asia. Of the top twenty fishing countries, ten are countries in Asia with a high or medium risk of modern slavery (Walk Free 2018). A contributor to this is employment opportunity and poverty. For example, the Philippines has emerged as Asia's third fast-growing economy (Cabuenas 2018), yet there remains a persistently high poverty rate among marginalized sectors, including fisherfolk, farmers, migrants, and the rural poor (Brillantes et al. 2019). Difficulty in finding work can lead to increased susceptibility to coercive practices (Mason 2017). Broker agents travel to countries and offer an opportunity to work on a fishing trawler for several months to earn around 1,500 USD. Once the job offer is accepted, fake documents are forged to smuggle migrants across the border and onto fishing vessels.

On board these vessels, people may stay on boats without docking for years at a time. They are provided little food and water while working 20-hour days. Sexual and physical abuse is rampant (McDowell et al. 2015). Enslaved people are chained to the boat as punishment and whipped with stingray tails. Victims described illness, psychological abuse, and the death of crewmates while on board (ILO 2023). Going to the police is rarely an option: if the boat docks, going to the police could put the migrant worker in jail, deported, or sent back to their abusers (Mason 2015). If freed, some struggle to return home, where they are still unable to find work and are susceptible to being trafficked onto a vessel again (Mason 2015).

To protect against these worker abuses and illegal fishing, the Philippines has partnerships with conservation groups to monitor illegal fishing, as well as established major reforms with the Bureau of Fisheries and Aquatic Resources (BFAR) and the Environmental Defense Fund. The Global Slavery Index gives the Philippines a government response rating of BB. The Global Slavery Index was created by the international human rights group 'Walk Free.' The organization works with the International Labor Organization and the International Organization for Migration to develop modern slavery estimates (Walk Free 2018). The rating system ranges from D, the least effective response to modern slavery, to AAA, the most effective response system. The Philippine index score of BB indicates the introduction of policy measures addressing modern slavery, including victim support services, a criminal justice framework that criminalizes modern slavery, and protection for those vulnerable to slavery; yet other policies that may criminalize or penalize victims of slavery (Walk Free 2018).

While the fishing industry is heavily regulated, enforcement mechanisms are limited or lacking. In the past, slavery on fishing vessels has been traced by individual organizations that interviewed dock workers, fishing vessel captains, and formerly enslaved people (McDowell et al. 2015). Individual organizations have thus successfully traced vessels, while governments may struggle to do the same due to regulatory barriers. For example, for U.S. Customs and Border Patrol to investigate a shipment, they must receive a well-informed tip that shows reasonably, but not conclusively, that slave labor was used in the supply chain of the product (U.S. Customs 2023). The key to changing modern slavery on fishing vessels is enforceability, which can be implemented by increasing investments into seafood traceability technologies throughout the supply chain beyond current limited approaches.

3. Philippine fisheries production and labor force

Globally, the Philippines is the 8th largest producer of fish, invertebrates, and seaweed from capture fisheries and aquaculture operations (BFAR 2021), representing ~2% of total world production in 2021 (FAO 2022). Fishing and aquaculture contribute approximately 4.5 billion USD to the Philippine economy, inclusive of a total international export valued at 1.1 billion USD (BFAR 2021). The United States is the largest destination for Filipino fisheries and aquaculture products, accounting for 27.7%

of exports, followed by Japan and China, at 12.6% and 10.6%, respectively. Fisheries products are also Filipinos' primary animal protein source, making up ~11% of the average person's total food intake and only exceeded by rice products (BFAR 2021).

The Philippines' seafood industry is supported by a registered labor force of approximately 2.2 million people (5% of the national labor force), of which more than half work in the capture fisheries sector (BFAR 2021; PSA 2022). Fisheries workers' annual income ranges between 615 to 13,635 USD (34,279 to 759,293 PHP) (BFAR 2021). Poverty rates are typically higher for fisherfolk than any other primary sector in the Philippines, with the annual incidence between one-fourth and one-third of the labor force (PSA 2022). The high poverty rate and low annual income in fisheries can force Filipino fisherfolk to take any work available, including as migrant workers with fisheries operators that may engage in illegal fishing, labor abuses, and modern slavery (Tickler et al. 2018; Asis 2019). Data on migrant fisheries workers is limited, yet some information is available. For example, an annual average of 6,600 Filipinos work abroad, recruited by fee-charging agencies primarily with operators in Taiwan and China, with contracts of 12 months and a salary of 3,000 USD (Asis 2019). This does not include agency placement fees that range between 2,500 and 4,200 USD per placement as reported by workers, inclusive of 'anti-runaway' deposits of 1,000 USD (Asis 2019).

4. How eDNA detection can help combat illegal fishing and modern slavery in the Philippines

Illegal fishing activities and modern slavery in fisheries co-occur in part because culpable vessels aim to maximize the profitability of fishing by staying out at sea as long as possible to harvest increasingly scarce resources (Mackay et al. 2020). As fish resources become scarcer, demand for cheap labor increases, fueling a troublesome cycle (Brashares et al. 2014). Furthermore, by staying out at sea longer and venturing farther to pursue distant stocks, regulations to combat illegal fishing or forced labor become logistically more difficult to enforce.

Fortunately, growing attention on the concurrent challenges of illegal fishing and slavery at sea, both in the Philippines and globally (see Mendoza et al. 2016), has catalyzed the call for the creation or strengthening of national policies, international conventions, and corporate social responsibility commitments (Sutton and Siciliano 2016). These efforts include reinforcing anti-trafficking laws for overseas violations, increasing foreign assistance programs aimed at building local enforcement capacity, and investing in and subsidizing technologies for both the private and public sectors to monitor and trace the seafood supply chain, including the potential of eDNA-based traceability tools.

eDNA metabarcoding tools, in tandem with other emerging technologies, are positioned to aid in efforts to combat illegal fishing and modern slavery in two ways (Figure 1). First, vessels identified by satellite-based monitoring efforts (DeSombre and Barkin 2011; McCauley et al. 2016; Taconet et al. 2019) as suspects of illegal fishing can be reported to authorities as the vessel arrives at port. In addition to inspecting fishing routes and catch documents, eDNA metabarcoding testing of catch composition can be used to not only identify species caught (Willette et al. 2021a) but can also provide geographic information on where the fish were captured. Specifically, eDNA approaches can include Single Nucleotide Polymorphism (SNP) markers that can distinguish the wild population or stock origin (Bernatchez et al. 2017; Barth et al. 2019). Including SNPs in eDNA screening to discern the geographic origin of a landing could be particularly helpful for investigating the co-mingling of fish from transshipments or of fish captured in protected waters. A second, more tangential possibility is that eDNA metabarcoding could be used as a modern forensic tool to direct screen water samples from fishing vessels for missing persons, an idea building upon preliminary efforts by researchers at the Center for Human Identification at the University of North Texas Health Science Center (Bus et al. 2019). In their pilot work, Bus et al. (2019) created a humanitarian DNA database to identify missing persons suspected to have been trafficked or in forced labor that, in coordination with the missing person's families, could then be used to screen for genetic matches in internationally shared DNA data. Although previous eDNA metabarcoding research in fisheries does not screen for human DNA, human DNA could be in samples given that eDNA is shed by all living organisms, including fisheries workers. Lastly, recent advances in protocols using eDNA metabarcoding have reduced the time it takes to obtain sequence results from a water sample to less than 24 hours (Ames et al. 2021; Willette et al. in preparation). This enables scientists, resource managers, and regulators to collect and obtain results quickly so they may make monitoring and control decisions while seafood is in the supply chain.

5. Policy recommendations

The Philippines has numerous existing laws that have been used to address the challenges of illegal fishing and forced labor within the fishing industry, many of which align with several U.S. policies and regulations similarly aimed at illegal fishing and forced labor at sea (See Table 1). Philippine laws are also aligned with analogous European Union policies, such as the Common Fisheries Policy, and international regulations, such as the Food and Agriculture Organization of the United Nation's Port State Measures Agreement. Precedence for policy action, matched by technological innovation, includes the recent U.S. Uyghur Forced Labor Prevention Act of 2021. This act directs U.S. Customs and Border Protection to assume all products and components from the Xinjiang Uyghur Autonomous Region are made with forced labor; thus, importing companies have the burden to prove forced labor was not used (U.S. Customs 2023). The Act has an impact on the supply chain of Southeast Asian countries that must pivot to ensure long-term access to the U.S. marketplace (Fox 2022). The adoption of eDNA metabarcoding methods and other emerging technologies can aid the Philippines, as well as other fish-producing and fish-importing nations, in facilitating regulatory compliance of strengthened forced labor and illegal fishing policy by seafood supply chain stakeholders (Figure 1). Such technologies are already being piloted in global fisheries (e.g., Willette et al. 2021a), yet their rapid adoption and application at scale require government action and support from foreign fisheries assistance programs to help reduce technology dissemination costs, ensure uniform and global standards are set, and reduce illegal fishing faster.

Table 1. Philippines policies, descriptions, and relevance to present policy brief.

Law/Policy	Brief Description	Relevance to recommendations in policy brief
Republic Act No. 10654, Section 14, 90, 116, 119	A sustainability monitoring, control, and surveillance system shall be established, must fish in a national jurisdiction, if sailing in distant waters, must bring a fisheries observer, must use a fishing vessel monitoring system at all times.	Implements sustainability and force labor monitoring systems, such as demanding that an observer compliant with RFMO conservation be on distant water vessels, which opens the door for writing eDNA technology and other traceability methodologies to be written into the law through monitoring, control, and surveillance systems.
Philippines Constitution 1987, Article XIII Section 3	The State shall afford full protection to labor, local and overseas, organized and unorganized, and promote full employment and equality of employment opportunities for all. It shall guarantee the rights of all workers to be entitled to security of tenure, humane conditions of work, and a living wage. They shall also participate in policy and decision-making processes affecting their rights and benefits as may be provided by law.	Worker protection rights are not only for Filipino citizens but for foreign nationals as well. It entitles all workers to humane work conditions and living wages which is the basis for eradicating modern slavery.
Penal Code, Article 272 & 274	The penalty of prison shall be imposed upon anyone who shall purchase, sell, kidnap or detain a human being for the purpose of enslaving him, or upon anyone who, in order to require the payment of a debt, shall compel the debtor to work for him against their will.	This law protects against several methods of entrapment into modern slavery, such as kidnapping or detaining individuals to enslave them. Modern slavery often entails the usage of debt bondage which keeps workers in harsh working conditions for longer to pay off their debts. This law also prevents the debt agents from compelling debtors to work for agents against their will.

United States Policy Table:

Law/Policy	Brief Description	Relevance to Policy Brief
Tariff Act of 1930	No products may be imported if forced labor is used in its production, even if it is necessary to meet consumer demand.	If fish coming from the Philippines is found to have been caught using slave labor, the US will not allow it into its borders - this would have a negative effect on the Filipino economy, which depends heavily on the fishing industry.
Magnuson-Stevens Act	Prevents overfishing, directs the United States to strengthen international fisheries management organizations, directs the United States to address illegal, unreported, and unregulated (IUU) fishing and bycatch of protected living marine resources.	Allows for the strengthening of fishing management across the globe and addresses illegal fishing based on scientific evidence. Paves the way to argue for increased funding for satellite monitoring and eDNA technology.
Sustainable Fisheries Act	Strengthened requirements to prevent overfishing and rebuild overfished fisheries, set standards for fishery management plans to specify objective and measurable criteria for determining stock status, and added three new national standards to address fishing vessel safety, fishing communities, and bycatch.	eDNA technology can help protect against both overfishing and forced labor, and in setting standards and strengthening requirements to prevent overfishing, this allows room for eDNA technology to be implemented into the law in such a way that it becomes a requirement to use similar traceability methodology to prove that fish was legally and sustainably caught.
Lacey Act of 1900	Declares that it is unlawful to import and sell fish and other wildlife in violation of state, federal, or foreign law.	All fish being sold in the United States must comply with laws on the local and international level, implying that any fish caught using forced labor cannot be sold in the United States.

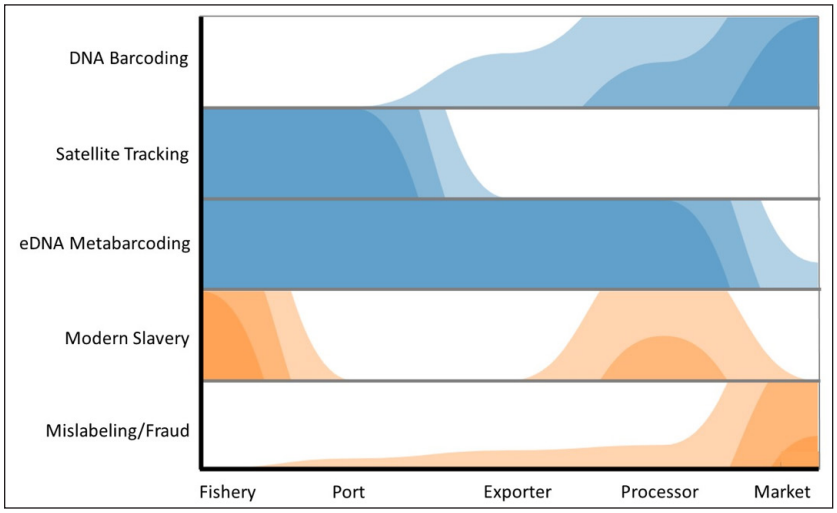

Figure 1 – Potential application and utility of monitoring and traceability technologies (blue) and risk level of illegal activities (orange) at points in the seafood supply chain. Height and darker color intensity signify the greater potential of technology or higher risk level of illegal activity.

The following are three recommended actionable items to facilitate the uptake and broader implementation of eDNA-based traceability tools that can help combat illegal fishing and modern slavery:

1. Build infrastructure further – The Philippine Genome Center is a prime example of government investment in genetics infrastructure to develop and advance genome-based applications. However, to facilitate adoption at scale in both the private and public seafood sectors, efforts should extend to 'democratizing' eDNA metabarcoding capabilities. This is now achievable with the advent of pocket-size eDNA sequencing devices (e.g., Oxford Nanopore Technology MinION), cold chain-free library preparation kits, and fully portable, battery-powered molecular laboratories that can fit into two suitcases and can be assembled at a fraction of the cost of a traditional laboratory facility (Ames et al. 2021, Willette et al. in preparation). These tools are versatile and free users from the need to have access to a traditional laboratory, potentially enabling eDNA-based species identification on fishing vessels, in ports, and within seafood processing plants, as well as within regional government and academia facilities.

2. Effectively train technical staff – The implementation of emerging technologies includes eDNA metabarcoding in the fight against illegal fishing and modern slavery, requires growing a workforce of highly skilled young professionals from across the science, technology, engineering, and math (STEM) fields. Past perceptions of employment in fisheries as a lower-skill occupation are increasingly becoming invalid, given that fisheries of the 21st century are changing. Impending jobs will require creativity and innovation to address the concurrent economic, ecological, and societal challenges facing fisheries. Upgrading existing national and international fisheries pipeline programs should be a first step in achieving this outcome and has already begun. For example, the National Fisheries Research and Development Institute (NFRDI) Students' Training Support (STrainS) program provides immersive, on-the-job, or internship-based training in chemical and molecular testing for high school and college students as a catalyst to transition into the fisheries profession. Expanding such programming would spur further innovation and increase the resilience of the fisheries workforce.

3. Financial and societal incentives – The challenges of illegal fishing and forced labor cannot be solved by technology alone, yet the extent to how fast and how broadly technology can help facilitate reaching solutions will require creating financial incentives. If addressing illegal fishing and forced labor are indeed national priorities, then infrastructure and training needs must be underwritten in government budgets and matched by foreign fisheries assistance programs. Furthermore, forced labor is becoming a more salient issue in the media. As it does, public opinion demands that companies are held accountable for their supply chain. Significant political change is driven by public opinion. Organizations working in international trade have already begun to see an increase in the number of corporations requiring assistance in tracing their supply chain to ensure they maintain public approval and can legally sell their product in the global marketplace, including the U.S. and E.U. eDNA-based traceability and other emerging technologies are well-positioned to aid in such efforts.

CONFLICT OF INTEREST

To the best of our knowledge, no conflict of interest exists.

ETHICS STATEMENT

No animal or human studies were carried out by the authors for this paper.

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