Big fish in a small plate - a bigeye's journey toward a head-to-tail utilization in San Diego

A Capstone Submitted to Scripps Institution of Oceanography at the University of California San Diego

In Partial Fulfillment of the Requirements for the Degree of
Master of Advanced Studies in
Marine Biodiversity and Conservation

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August 8, 2019

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EXECUTIVE SUMMARY

Today, world capture fisheries have reached their maximum capacity and the future of seafood supply is threatened by global environmental factors such as climate change, ocean pollution, acidification, and overfishing. Waste reduction, or a fuller utilization of every part of the wild caught fish, represents an opportunity to meet the increased demand in seafood consumption without further stressing the resource, while helping to sustain high standards fisheries by adding value to the landed catch. In order to better manage waste, it is necessary to identify and quantify by-raw material (waste to be repurposed) along the seafood value chain. This project describes the bigeye (*Thunnus obesus*) fresh tuna market in San Diego using a metabolism approach. Specifically, the goals were to: (1) describe the bigeye tuna supply chain in San Diego, (2) quantify where losses are occurring, and (3) briefly describe opportunities to utilize by-raw materials. The project serves as a proof of concept that applying this method can successfully identify and follow the biomass throughout a particular seafood system. Every step of the value chain was included, from harvest at sea, to the processing facility, to the seafood counter. For the year 2018, this research estimated that the fishery provided 596 metric tons (MT) of fresh seafood to the local market while an additional 187 MT of wild resource was lost along the way with some at sea and some concentrated at the processor. Of the 187 MT of loss, 136 MT of losses happen at sea and consist of catch released alive or dead, lost bait, guts and gills, and 51 MT of bigeye by-raw material are left in the processing facility and comprise head, collar, tail, carcass, skin and bloodline. While the model shows that most of the losses occur at sea and consist of by-catch, it is important to note that by-catch data from the Western and Central Pacific longlining fishery was used as a proxy and may not be representative of West Coast fisheries that have different fishing grounds. Therefore, the robustness of this number should be tested in the near future when West Coast by-catch data become available. Bigeye yield is known by the industry to be ca. 50% but because losses are diffused along the value chain only 18% of by-raw material is shown by this study to be found at the processing facility, this includes head and tail currently used as lobster bait or turned into compost. There are a number of additional uses for bigeye by-raw material. To move towards a full utilization of the fish, the industry could target unused and actionable by-raw material such as tuna skin for leather, in addition to exploring new processing and marketing strategies for the lower grade filets that currently are under-sold or eventually discarded. Despite the relatively small size of the San Diego bigeye fishery, the integration of all data streams of the supply chain demonstrated that this approach could be replicated to evaluate by-raw materials in other fisheries or locations. If exploring culinary and non-culinary uses of our wild-caught fish is an important step to move toward greater sustainability, further research at a larger scale as well as a regulatory framework analysis are needed to understand and estimate the impact of a full utilization movement for marine conservation in California.

INTRODUCTION

A. Background and Problem Statement

San Diego tuna fisheries – San Diegans have been fishing for tuna since the 1880s and the industry has brought jobs and wealth to the region as millions of cans of yellowfin (*Thunnus albacares),* skipjack (*Katsuwonus pelamis)* and albacore (*T. alalunga)* were shipped globally in the 20th century. For many years San Diego had its own 'cannery row' and was known as the 'tuna capital of the world'. In the first part of the last century, the seafood industry peaked at the third place in terms of revenue generation for the county, behind the Navy and aircraft industry (Rohit, 2018). However, as San Diego's tuna fisheries turned to mechanized purse seining in the late fifties, economic forces began to push U.S. continental processing operations overseas to take advantage of greater resource availability, lower labor costs and tax benefits (Sakagawa, 1991, Thomson 2015). This resulted in the decline of San Diego's tuna fleet and associated shore-side infrastructure.

Globally, the average annual increase in food fish consumption outpaces population growth, reaching 170 million metric tons in 2016 (FAO, 2018). 272,000 metric tons of tuna were imported to the United States in 2018 which represent more than 80% of the nation seafood consumption (NOAA, 2019). There is clear opportunity to develop domestic fisheries for tuna while meeting sustainability goals, including avoiding overfishing and ensuring mitigating bycatch as required by the Magnuson-Stevens Act (MSA) and recommended by the FAO code of conduct (FAO, 1995). Optimum yield, efficiency and nutritional value are among other MSA and FAO principles to be considered when developing domestic fisheries. While this does not necessarily mean local fisheries will not be competitive, lower priced imports put on pressure on fishing families to add value to products and create innovative ways of sustaining their livelihoods (Olson, 2014).

As demonstrated by the popularity of the Tuna Harbor Dockside Market, San Diego's open-air seafood market, there is a recent effort underway to revitalize the commercial fishing industry in order to provide fresh heathy protein, lower industry's carbon footprint, support local economies and help reduce the seafood trade deficit (Talley, 2016). Currently, San Diego's commercial fleet consists of about 130 vessels. Bigeye tuna (*T. obesus*) is caught by a few of these vessels but rank in the first position in terms of tonnage landed. For the year 2018, it accounted for 416 MT (31% of all landings). These fisheries contribute to the local economy by providing fresh seafood harvested under strict MSA standards. In addition, a few Hawaii permitted boats have recently started to land their catch in San Diego, providing another opportunity to look at the re-emerging tuna supply chain and to evaluate ways to maximize profit to local fishing economies while minimizing waste production and disposal.

Wasted seafood – filling the protein gap? – The extraordinary chemical and biological diversity observed in the marine environment makes the ocean an important source of high added value compounds which can be used widely in our societies (Ferraro, 2010; Kim, 2006). In human history, seafood has played an important role in nutrition and in particular as a source of healthy protein. A striking example is the current USDA Dietary Guidelines that recommend consuming 8 ounces of seafood per person per week, which would require doubling the US supply (Love, 2015). A promising approach to help fill the gap and sustain our local fisheries without further depleting the global fish stocks is to increase the efficiency in the seafood supply chain by utilizing all parts of the landed catch and prioritize food uses, by promoting the use of underappreciated species, and by improving the misinformation about landed species (Love, 2015; Gosh, 2016).

There could also be an opportunity for tuna fisheries to adopt a 'full utilization approach', following a new utilization movement led by the Icelandic fishing industry who already successfully applied the concept to their commercial fisheries (Sigfusson, 2016). The San Diego fishing community could achieve greater profit and San Diego fisheries could better contribute to human health by providing additional fresh protein, and by supporting the increasing demand without further stressing the resource (fishing effort).

To begin with, meet your trash – Loss could be avoided either by reducing waste production in the first place, or by making use of the unavoidable waste occurring along the supply chain. The term by-raw material is used purposely in the following pages to highlight the potential for use of what is often considered just as waste to be disposed of. In terms of loss in the seafood supply chain, data available in the US is of variable quality. The work of the Center for a Livable Future at John Hopkins University, for example, showed that postharvest handling and storage and processing and packaging are areas where better loss estimates are needed (Love, 2015). Having a better understanding of the loss and where it occurs is the first step towards a full utilization. To cite a local example, at Catalina Offshore Products, a local processor, grade A tuna finds its way easily to market while lesser tuna grades are sold at lower price points or frozen and stored for later sale and if not sold, eventually discarded (Dave Rudie, pers. comm., 2019). Fish by-raw material utilization is limited: the head, tail, carcass, skin and bloodline are usually discarded for the most part. These portions of the fish are likely to end up in a landfill and potentially contribute to underground water pollution and greenhouse gas emissions. While fish by-product (product made of by-raw material) utilization in the U.S. is gaining increased mainstream attention (Johannesson and Sigfusson, 2018), identifying current uses of bigeye by-raw material is part of the study but quantifying by-products is not.

In order to better understand the new San Diego tuna value chain, this capstone project will (1) describe the bigeye tuna supply chain in San Diego using a metabolic approach, (2) quantify if and where waste is produced, and (3) briefly discuss opportunities to utilize this untapped resource. A mass balance of the supply chain will be realized to that purpose.

B. Specific Objectives

The overarching goal of this project is to investigate ways to maximize the value and minimize loss in tuna fisheries operating out of San Diego. Without increasing the fishing effort, this project strives to promote the full utilization of the fish by understanding where inefficiencies occur along the seafood supply chain and creating valued product out of currently wasted or undervalued parts (including non-edible parts). This will highlight opportunities to increase profitability from the catch and perhaps to maximize protein for every fish landed. This project focuses on bigeye landed in San Diego and processed at Catalina Offshore Products providing an end-to-end look at the tuna supply chain. This approach also contributes to reestablishing the connection between human consumption and marine ecosystems, by treating bigeye as a food production system (Helvey, 2017; Olson 2014). Catalina Offshore Products and the vessels that land tuna in San Diego have generously offered to share their operations, insights and data.

The specific goal of this project is to estimate the amount of waste or potential by-raw material occurring at every stage of the supply chain from ocean harvest to seafood counter in the deep-set longline fishery (DSLL) which lands bigeye in San Diego. The approach taken in this project can be used not only to inform strategies to reduce loss in local tuna fisheries but in other fisheries as well. It is my hope that this project will compel the prioritization of loss reduction actions as well as further research on reducing loss in our seafood system.

The geographic scale of the study encompasses the administrative borders of San Diego county which represents 73 % of California bigeye landings (PacFIN, 2019). The county bigeye landings are exclusively situated in San Diego Bay. The study's boundaries are also defined by the existing management system and existing fishing methods (DSLL) under which bigeye is caught and landed in San Diego. Bigeye fishery is managed by the United States under the Highly Migratory Species (HMS) management plan of the Pacific Fishery Management Council (PFMC). Because DSLL vessels landing bigeye in San Diego fish in the high seas east of the 150 deg W. longitude, the fishery is also regulated by the Inter-American Tropical Tuna Commission (IATTC).

METHODS

A. Modelling approach

The modelling approach supports a biophysical understanding of a socio-economical system. It is derived from the product approach to Material Flow Analysis (MFA) where a system maintains organized exchanges with the environment (Brunner, 2016; Cencic 2008). It is a well proven process mapping method used in food producing companies (Olsen, 2010) which also scales successfully to larger systems. The approach is based on a schematic representation of supply chain activities where a commodity undergoes a number of transformational processes. By using this systemic approach, we can describe a complex system such as the ones encountered in the seafood industry and understand the interactions the sector's activities have with its economic and natural surroundings.

The model is based on the principle of mass conservation and defined as a simplified system of flows and processes (figure 1). To describe the model in a mathematical way, I used two simple process equations where inputs and outputs are flows.

(i) Balance equation: $\sum inputs = \sum outputs$

(ii) Linear equation: $\begin{cases} output_1 = transfert\ coefficient_x \times \sum inputs \\ output_2 = transfert\ coefficient_{1-x} \times \sum inputs \end{cases}$

The model includes all landings in San Diego. However, once the fish is landed, this project focuses only on those tuna that are sent to one processing facility which represents the bulk of the local market (81%).

A rapid assessment of the bigeye supply chain in San Diego was conducted in order to design the model. The assessment included looking at the type of fisheries landing bigeye in California through the Pacific Fisheries Information Network (PacFIN), and looking at the buyers and processors for these fisheries. From there, two different methods were used to collect data available for the year 2018. First, data for San Diego bigeye landings was extracted from commercial landing tickets and made available by both NOAA Southwest Fisheries Science Center (SWFSC) and the California Department of Fish and Wildlife (CDFW). Second, data was collected at one specific processing facility where sales were readily available. The accuracy and quality of this data subset can be considered high as the processor keeps track of every product sold including weight and format. The same goes for the landings data which are processed raw and consolidated by both NOAA SWFSC and CDFW.

Following the initial assessment, a determinist model for bigeye was developed with two types of equations: the variable equations (flows), and the balance equations (processes). Using a mass balance approach was helpful as it supported a finite number of unknown variables encountered during the project.

B. Processes and flows

The level of detail of the model is meant to be representative of San Diego fresh tuna supply chain and relevant to describe the resource extraction and transformation along the value chain. The processes can be categorized into two categories: fishery at sea and fish at the processing facility. To quantify the use of bigeye, flows can be grouped into four categories: import to the system from the natural environment (I_N); export from the system to the natural environment (E_N); export from the system to the economic environment (E_E); and flow within the system boundaries (F). Processes and flows are described in tables 1 and 2 respectively.

Fig. 1. The bigeye supply chain in San Diego for 2018. Blue boxes represent processes at sea; gray boxes represent processes on land. Bold flows are for potential losses.

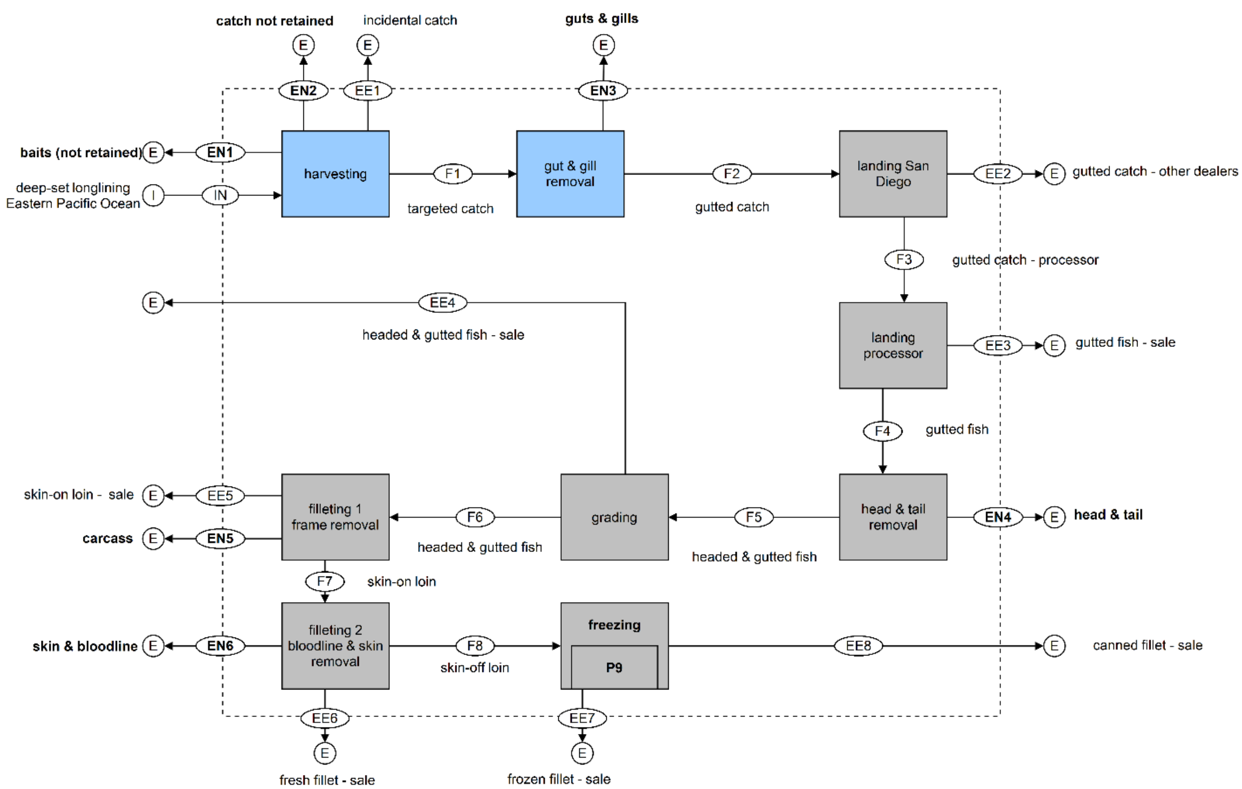


Table 1. List of processes included in the system describing bigeye supply chain in San Diego.

Processes	
Short symbol	**Name**
P1	harvesting
P2	gut & gill removal
P3	landing San Diego
P4	landing processor
P5	head & tail removal
P6	grading
P7	filleting 1 frame removal
P8	filleting 2 bloodline & skin removal
P9	freezing

Table 2. List of variables (flows) included in the system for 2018. The list includes the origin and destination of each flow. Note that "natural ecosystem" as used here represents material returned to the ecosystem, either to the sea or to the soil through composting or landfilling processes

Flows			
Short symbol	**Name**	**From**	**To**
IN	deep-set longlining Eastern Pacific Ocean	I,natural ecosystem	P1,harvesting
F1	targeted catch	P1,harvesting	P2,gut & gill removal
F2	gutted catch	P2,gut & gill removal	P3,landing San Diego
F3	gutted catch – processor	P3,landing San Diego	P4,landing processor
F4	gutted fish	P4,landing processor	P5,head & tail removal
F5	headed & gutted fish	P5,head & tail removal	P6,grading
F6	headed & gutted fish	P6,grading	P7,filleting 1 frame removal
F7	skin-on loin	P7,filleting 1 frame removal	P8,filleting 2 bloodline & skin removal
F8	skin-off loin	P8,filleting 2 bloodline & skin removal	P9,freezing
EN1	baits (not retained)	P1,harvesting	E,natural ecosystem
EN2	catch not retained	P1,harvesting	E,natural ecosystem
EN3	guts & gills	P2,gut & gill removal	E,natural ecosystem
EN4	head & tail	P5,head & tail removal	E,natural ecosystem
EN5	Frame	P7,filleting 1 frame removal	E,natural ecosystem
EN6	skin & bloodline	P8,filleting 2 bloodline & skin removal	E,natural ecosystem
EE1	incidental catch	P1,harvesting	E,economic ecosystem
EE2	gutted catch - other dealers	P3,landing San Diego	E,economic ecosystem
EE3	gutted fish – sale	P4,landing processor	E,economic ecosystem
EE4	headed & gutted fish - sale	P6,grading	E,economic ecosystem
EE5	skin-on loin - sale	P7,filleting 1 frame removal	E,economic ecosystem
EE6	fresh fillet – sale	P8,filleting 2 bloodline & skin removal	E,economic ecosystem
EE7	frozen fillet – sale	P9,freezing	E,economic ecosystem
EE8	canned fillet – sale	P9,freezing	E,economic ecosystem

C. Data collection

Fishery, at sea – The amount of targeted catch (F_1) is the starting point of the calculation and is derived from the number of San Diego commercial landings (CDFW, 2019). Because commercial landing tickets do not specify the dressed state of the fish (whole or round vs gutted and gilled), the fish is considered as round when landed. However, fresh bigeye is landed gilled and gutted. Therefore, an additional step was required to obtain the full weight of the catch, including gills and guts (table 5). The unknown variable – guts & gills (E_{N3}) – is then the result of the balance equation applied to gut & gill removal (P_2). The catch not retained (E_{N2}), incidental catch (E_{E1}), and baits not retained (E_{N1}) are based on the targeted catch with ratios derived from the 2017 SAFE Report from the Western Pacific Regional Fishery Management Council (WPRFMC, 2018) as well as the expertise of the observer program team from NOAA fisheries West Coast Region (NOAA WCR pers. comm. 2019)[1] (Appendix). The Pacific sardine (*Sardinops sagax*) is commonly used in the U.S. DSLL fishery and is used as a proxy in this study, with an average weight of

[1] 2017 SAFE report from WPRFMC is used as a proxy for by-catch data because 2018 U.S. West Coast SAFE report for highly migratory species does not include by-catch data for confidentiality reasons. However, discussions with experts from NOAA West Coast Region observer program allowed me to increase the accuracy of the model by using west coast numbers for blue shark (*Prionace glauca*) by-catch which has a significant impact on the mass balance as blue shark is the predominant species not retained in DSLL fishery operating out of San Diego.

0.18 pounds (NMFS, 1997). Finally, the wild resources extracted by the fishery to cover San Diego bigeye market (Import from Natural ecosystem - I_N) is the result of the mass balance equation applied to P_1, harvesting. All ratios, yields and data sources are available in tables 3 and 5.

Table 3. Ratios used in the mass balance equation of the harvesting process.

ratios (based on mass)		**data source**
targeted catch to total catch	0.61	derived from WPRFMC 2018, NOAA WCR pers.comm. 2019
non targeted but retained catch to total catch	0.26	derived from WPRFMC 2018, NOAA WCR pers.comm. 2019
released catch to total catch	0.13	derived from WPRFMC 2018, NOAA WCR pers.comm. 2019

ratios (based on individual)		**data source**
cost-per-unit-effort CPUE (for 1000)	4.2	WPRFMC 2018
baits not retained to total baits	0.99	derived from WPRFMC 2018

Fish at the processing facility - Raw data was extracted from the 2018 sales' report from the processor. Next, each product was catalogued depending on the number of process stages required and grouped as such (Table 4). When data was not specified by species (bigeye or yellowfin), a ratio of 85/15 was applied (Dave Rudie, person. Comm.,2019). Once the sales (Export to the Economic ecosystem - E_{En}) were plugged into the model, the discarded parts (Export to the Natural ecosystem - E_{Nn}) were derived by applying the corresponding yields used by the industry (Table 5).

Table 4. Categorization of product sales. Each product has been grouped (if necessary) and matched to one specific variable of the system.

bigeye sales & categories

name of the product	**system variable**
bigeye head on bigeye bulk sale Head on	EE3, gutted fish - sale
bigeye tuna H&G bigeye grill grade H&G bigeye sashi H&G	EE4, headed & gutted fish - sale
bigeye loin skin on	EE5, skin-on loin - sale
bigeye loin skin off bigeye tuna belly bigeye poke chunks	EE6, fresh fillet - sale
bigeye frozen loin skin off bigeye internet frozen tuna portions	EE7, frozen fillet - sale
bigeye frozen inventory from loin skin off	EN7, expired stock
bigeye canned tuna	EE8, canned fillet - sale

Table 5. Yields used in mass balance equations of processes where fish parts are discarded.

yield		relevant process	data source
round to gilled & gutted	0.91	gut & gill removal	derived from Langley. 2006
gilled & gutted to headed & gutted	0.88	head & tail removal	industry
headed & gutted to loin	0.72	filleting 1 carcass removal	industry
loin to fillet	0.85	filleting 2 bloodline and skin removal	industry

RESULTS & DISCUSSION

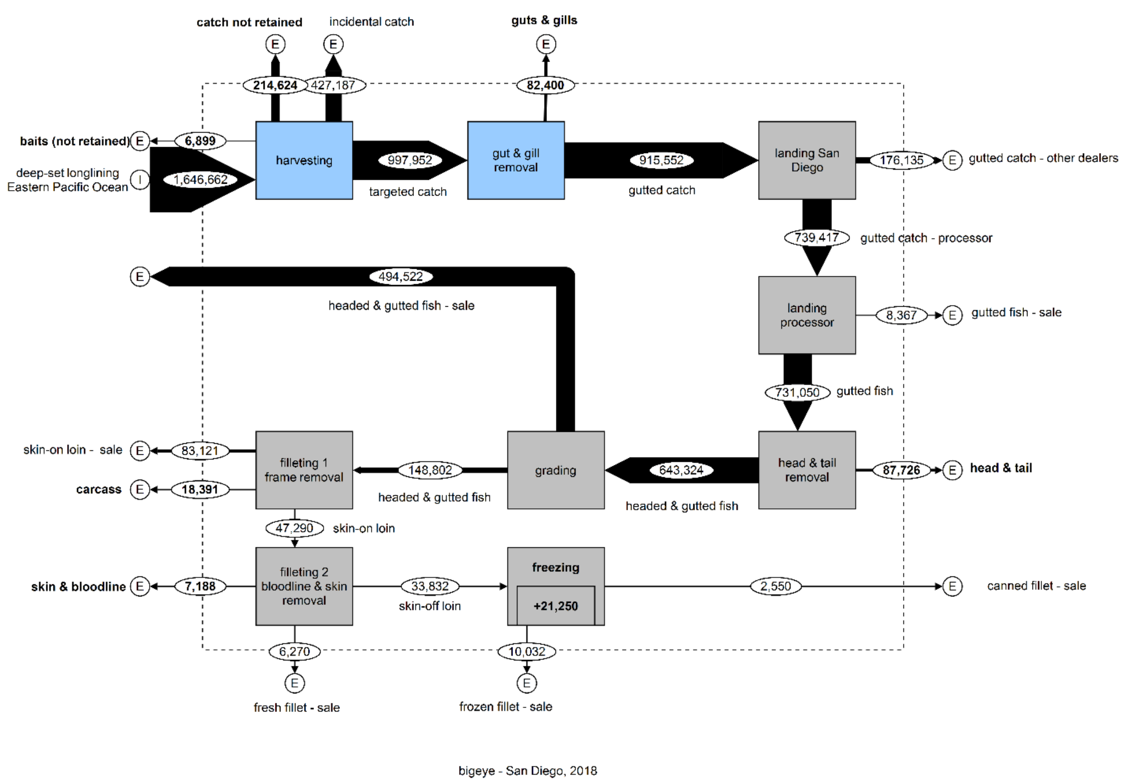
A. Seafood production

In 2018, 1340 MT of edible seafood was landed in San Diego by domestic fisheries (PacFIN, 2019). Bigeye accounted for 416 MT (31% of all landings).

In addition to bigeye, we can estimate that the fishery landed another 194 MT of other marketable species (or incidental catch) sold as food including mahi-mahi (*Coryphaena hippurus*), swordfish (*Xiphias gladius*), opah (*Lampris guttatus*) and monchong (*Brama japonica*) thus accounting for a significant part (in weight) of all landings in San Diego.

Now, these numbers represent the round weight of the fish and do not depict its use (yield) nor the associated bycatch (catch not retained) in the fishery. However, these considerations are fundamental to the understanding of the supply chain's efficiency as they are the steps with current wastage for human consumption and economies.

Figure 2. Mass balance for the San Diego bigeye supply chain (all weights in lbs).



B. Seafood losses at sea

As previously mentioned, commercial fishing routinely involves bycatch, both retained and not retained species. The U.S DSLL fleet fishing off the coast of California makes no exception to that. In addition to the retained catch (species discussed in the section above), the fishery also catches blue shark (*Prionace glauca*), which are mostly released alive (NOAA WCR person. commu. 2019)[2]. In 2018, 96 MT of fish were caught and released while fishing to supply fresh tuna to San Diego. However, this figure is expected to evolve as data on by-catch for the Eastern Pacific will soon be available, thus allowing us to fuel the model with numbers from this fleet instead of using substitute values from the Western and Central Pacific Ocean. Another 3 MT of pacific sardines are used in the fishery and therefore are not available to supply seafood to San Diego consumers (either lost at sea or associated with the released catch) (derived from WPRFMC, 2018; NMFS, 1997). For 2018, I estimated that the fishery succeeded to harvest 646 MT ($E_{E1}+F_1$) of seafood to supply San Diego fresh fish market. This figure represents 86 % of the effort put into fishing (747 MT (*IN*) of wild resources were needed to support bigeye local trade in San Diego).

As noted by Love (2015), in most seafood systems, the biggest loss occurs at sea and has important implications for the use of natural resources as well as for the fishermen. In this study, in 2018, I estimated that fourteen percent of the biomass entering the San Diego bigeye system is returned to the ocean without being utilized for human food or other industrial uses. Although this figure shows an efficient fishery, the losses potentially reduce the profitability to fishermen in terms of reduced value of landings, lost bait, wasted time in removing and discarding unwanted catch, and a reduced portfolio of marketable catch. I estimated that blue sharks and thresher sharks (*Alopia superciliosus, A. pelagicus*) account for more than 50% of the total losses at sea. While most of the sharks are released alive, the majority of mortality outcomes occurs within days of release (Musyl, 2019). This is why blue shark survival rate is currently being investigated (derived from WPRFMC 2018, NOAA WCR pers.comm. 2019).

C. Wastage limitation actions at sea

Bycatch prevention is the ideal way to improve the efficiency of the harvesting process: by reducing waste we would reduce the unnecessary inputs to the fishery. This could be achieved by improving selective processes to catch the targeted fish and could look at fishing methods/hooks that avoid catching sharks (modifying hook format, changing baits, removing of shallow set hooks, etc.). Another way of reducing loss could consist in making use of the unwanted catch, especially sharks if found dead, an issue being trying to be addressed by a NOAA Salton-stall-Kennedy grant project currently exploring the full culinary potential of discarded species in the DSLL fishery. Finally, the fishery could add value to its catch by using fish viscera and other offal which constitute a significant amount of the net fish weight, and contains a number of valuable material such as the omega 3 fatty acids eicosapentaenoic acid (EPA) and docosahexaenoic acid (DHA) as well as other high value enzymes. However, making use of this discarded part would require first the fishery to be able to proper store viscera and other offal onboard – and this would have to make up for loss of space for tuna.

D. Opportunities for a fuller utilization on land

By-raw material production in San Diego – In 2018, based on a 0.49 fish yield (round to fillet) commonly used in the industry (Dave Rudie, pers. comm., 2019), the U.S. DSLL fleet landed the equivalent of 222 MT of fillet weight in San Diego's bay. The losses, from gut and gill removal to the

[2] The West Coast DSLL bycatch ratio for blue shark is 3/100 bigeye

selling counter represent the other 51 % and are distributed as follow: 9 % or 42 MT on the boat (guts & gills); 42 % or 190 MT on land (11 % or 49 MT head& tail; 23 % or 101 MT carcass; 7 % or 39 MT skin & bloodline). (figure 3).

By-raw material production at the processing facility – At the processing facility, the fish undergoes an initial process stage where its head and tail are removed by a bandsaw. During this stage, the fish loses another 12% of its weight (due to the loss of head and tail). Then the individuals are lined up to be graded. During the subsequent process steps which refer to filleting the fish, each individual loses another 28% (the carcass), and 15% (the skin & bloodline) of its biomass[3]. For 2018, I estimated that the processor discarded 40 MT (12%) of head & tail, 19 MT (6%) of bones and trims, and 1.7 MT (0.5%) of skin & bloodline[4].

Now, the previous results presuppose the full use of the filet. But as shown in figure 1, there is a part of the fish that ends up being stored, the lower grade fillet. For 2018, I estimated that this potential food loss accounted for 10 MT. If added to other by-raw materials, the lower grade fillet would represent 16% of all tuna parts currently not utilized or underutilized.

Current uses of by-raw material – Bigeye is usually processed for sashimi, a format that only use the meat, resulting in an abundance of by-raw material. Looking at the yields, most of the waste is produced when the fish is filleted, and the carcass removed (about 23% of the whole fish). However, San Diego supply chain shows a more complex figure. Once landed, the fish (headed & gutted) is rapidly sold. Consequently, by-raw material leaves the system and spills over many other actors: from chef to consumers, locally and all over the continent. This would create another set of constraints if looking at uses opportunities at this level.

The 51 MT of by-raw material produced at the processing facility represented less than a third of bigeye's potential losses occurring on land. While most fish get its head removed by the processor (> 99 %), this number drops to 23 % when it comes to remove its carcass and drops even further when it comes to skin & bloodline removal (< 6 %). The biggest gap lies when the fish is filleted for the first time and represents 63 MT of bones and trims diffused among the chefs and consumers' level.

Head and tail, which represent most of by-raw material at the processor's, follows a separated waste stream whereas carcass, skin and bloodline do not. Segregated waste stream is the first step toward a better use of the fish as showed by the current example of bigeye's heads, used as lobster baits half of the year. The rest of the year and the other currently discarded fish parts are either composted or follow the traditional waste management system and are buried in San Diego city landfill.

Market for edible goods

Head

Looking at the predominant by-raw material available, there is a number of high value products that can be produced from fish heads and among them fish faces, tongues and cheeks. While it is difficult to guarantee an acceptable margin when processing head by hand due to high labor costs, recent technology hitting the market might help overcoming this barrier. Fish head is rarely used in American cuisine but is commonplace in various Asian dishes. It would be worth evaluating market opportunities for this type of

[3] The percentages here are given as yield which means they refer to the previous processing step and not the round weight.

[4] The percentages here refer to the total amount of bigeye processed at the facility on 2018

product considering that San Diego demographics shows a 11.8% of Asian population (County of San Diego, 2018).

Lower grade filet

Looking at the most economically valuable but underutilized part of the fish, the lower grade tuna, the next step could include a marketing strategy to promote its consumption, together with the development of a new product line, thus exploring its culinary potential. Catalina Offshore currently advertises this product as "grill grade" tuna but has not developed a large market for this tasty, but slightly off color filet. But as industry decisions are influenced by many factors, aligning benefits, costs, and impact on product quality is recommended prior to take action (Denham, 2015). To do so, a design brief should first be realized to define consumer market needs and the price the market will pay for the specific food product, followed by ideas generations, market research, product specifications, feasibility study, and a small-scale testing.

Other parts

Looking at the future of fish by-product, we can imagine a culinary engineering approach where backbone, collar and trims are processed and used to produce savory fish extract (to be used in fish sauce for example), or where cut-offs are successfully turned into surimi powder (Shih. 2003).

Healthcare Market

Another increasing trend in fish by-raw material is its use in the growing consumer healthcare market that develop midway between pharmaceutical and consumer goods companies.

Skin

Collagen is used in pharmaceutical, cosmetic and biomedical industries reducing the effect of ageing on skin and improving joint health. Bigeye's skin could be used as a source of marine collagen which provides an alternative to collagen derived from mammals. The latter being associated with several issues such as constraints for some religions and the transmission of diseases like bovine spongiform encephalopathy (BSE), or mad cow disease (Nalinanon, 2008). Marine collagen demand has been increasing over the past years in the United States.

Carcass

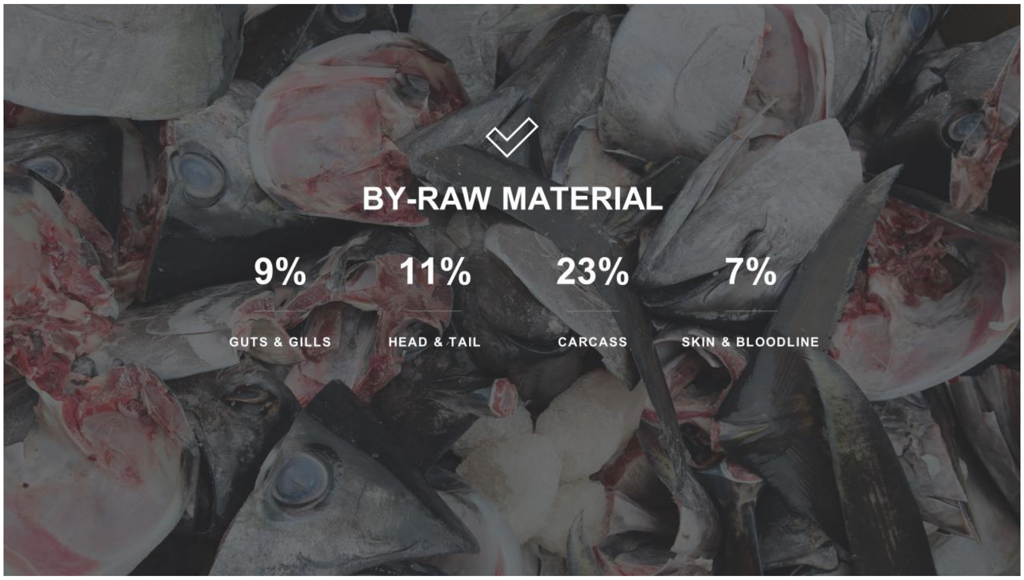
Due to high mineral content the tuna's bones can provide a natural source of calcium in for example, food, feed, or as supplement for animal consumption (Malde, 2010).

Material

Skin

Leather is a long lasting and natural material. In a quest to a more sustainable use of our resources, fish skin is gaining more attention as primary resource for leather used in fashion. 'Blue fashion' is an emerging sector of the blue economy where the fashion industry, extremely resource intensive, turns to more sustainable resource alternatives such as marine by-raw material like fish skin. Success stories in using fish skin to support fishing communities can be depicted all over the world, from small scales fisheries in Lake Turkana Kenya to the commercial fishing industry in Saudarkrokur Iceland. As a large fish with a smooth skin, tuna could expand opportunities for new styles and bigger pieces of garment such as bags or computer cases. As such it could contribute to the expansion of more sustainable leather markets and represents an actionable output of the project.

Figure 3 - percent of fish discarded



CONCLUSION

Fish entering the supply chain leaves only in either of two ways, sold as food, or as waste or by-raw material currently and for the most part being disposed of. I estimated that only 25% (EN_{1-6}/IN) of the resource entering the system leaves it without being used. This number means that either the value chain is very efficient at fully utilizing the fish, or losses are diffused outside the system boundaries. The truth likely lies between the two. If the fishery tends to retain every marketable catch, sold fish is still mainly used for its fillet. While this study has looked at bigeye's use only, broadening the model to other retained species will likely give us a better estimation of the supply chain sustainability. Another interesting way forward will be to deepen the study to all fish parts currently discarded (from all species, not just bigeye) at the processing facility. Doing so might increase the range of possibilities for new products if quantities or seasonality are among the limiting factors.

This project demonstrates the feasibility of using a metabolic approach to describe the bigeye value chain in San Diego and to differentiate all types of losses occurring along the way. Looking at weight and edible weight allows us to look at the fishery through the lens of a full utilization because it gives us a sense of resource available (biomass). In this instance and on a short-term basis, I would recommend prioritizing actions on the most valuable current underutilized part of the fish, the lower grade filets, and develop a product line for it. Another actionable output would be to use the skin to produce leather.

While this work looks closely at one relatively small fishery, the systemic approach used to quantify the waste can be applied and scaled to fishery, processing or location to evaluate sustainability in fisheries and target specific actions to strive towards full utilization. For these actions to be effective, it is necessary to broaden our understanding of incentives that would encourage stakeholders to adopt such new practices, and work across sectoral policies. Finally, further research at a greater scale as well as a regulatory framework analysis will be needed to understand and estimate the impact of a full utilization movement for marine conservation in California.

ACKNOWLEDGEMENTS

I would like to acknowledge the Center for Marine Biodiversity and Conservation (CMBC) at Scripps Institution of Oceanography, NOAA Southwest Fisheries Science Center (SWFSC) and Catalina Offshore Products for their support in this project. Special thanks to my advisory committee Dr. Sarah Mesnick (chair), Oriana Poindexter, Dave Rudie and Mark Helvey for their guidance and thoughtful inputs. I also would like to acknowledge the capable technical assistance of Charles Villafana from the observer program at NOAA West Coast Region and John Childers at NOAA SWFSC as well as Elizabeth Hellmers at California Department of Fish and Wildlife. Finally, I would like to thank with gratitude Scott Deely who kept me going. This year and capstone project would not have been possible without him.

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