جامعة الأخوين

ⵜⴰⵙⴷⴰⵡⵉⵜ ⵏ ⵓⵅⴰⵡⴰⵢⵏ

AL AKHAWAYN UNIVERSITY

School of Science and Engineering (SSE)

Design of Environmentally Friendly Fishing Sinkers, Lures & Floats

Final Report

Dounia Marbouh

Supervised by Dr. Naeem Nisar Sheikh & Dr. Alina Khasanova

© SCHOOL OF SCIENCE & ENGINEERING – AL AKHAWAYN UNIVERSITY

Design of Environmentally Friendly Fishing Sinkers, Lures & Floats

Student Statement:

I, Dounia Marbouh, hereby affirm that I have applied ethics to the design process and in the selection of the final proposed design. And that I have held the safety of the public to be paramount and have addressed this in the presented design wherever may be applicable.

Dounia Marbouh

Dounia Marbouh

Approved by:

Dr. Naeem Nisar Sheikh

Naeem Nisar Sheikh

Dr. Alina Khasanova

A Khasanova

Table of Content

1. Introduction 9

1.1. Context & Motivation 9

1.2. Methodology 10

2. Literature Review: 11

2.1. Fishing Sinkers: 11

2.2. Fishing Lures 12

2.3. Fishing Floats 13

3. Fishing Sinkers 14

3.1. Description of Fishing Sinkers 14

3.2. Effects of Lead Fishing Sinkers on Wildlife 15

3.3. Fishing Sinkers Loss Rate 17

3.4. Estimated Lost Fishing Sinkers 18

3.4.1.Example of Canada 18

3.4.2.Across the Globe 20

3.4.3.Sampling study in Morocco 21

3.4.4.Projection over the next decade 21

3.5. Alternatives study 23

3.5.1.Possible Alternatives 23

3.6. Weighted Decision Matrix 30

3.6.1.Criteria of the Weighted Decision Matrix 30

3. Fishing Lures 33

3.1. Description of lures 33

3.2. Lost fishing lures in wildlife 35

3.2.1.Rate of loss of fishing lures 36

3.2.2.Sampling study in Morocco 36

3.3. Effects of fishing lures on environment 36

3.3.1.Effects on water 36

3.3.2.Effects on fish species and waterbirds 37

3.4. Characteristics of Lures 37

3.4.1.Size 37

3.4.2.Color 38

3.4.3.Movement 38

3.5. Biodegradable alternatives 38

3.5.1.Corn Starch Based Bio-plastic 39

3.5.2.Gelatin Based Bio-plastic 40

3.6. Weighted Decision Matrix 41

3.6.1.Criteria of the Weighted Decision Matrix 41

3.6.2.Weighted Decision Matrix Discussion 42

3.7. Testing 42

3.8. Cost Analysis 43

4. Fishing Floats 44

4.1. Description of fishing floats 44

4.2. Effects of Fishing Floats on Environment 44

4.3. Weighted Decision Matrix 45

4.3.1.Weighted Decision Matrix Criteria 45
4.3.2.Weighted Decision Matrix Discussion 46
5. Steeple Analysis 48
6. Limitations & Future Work 50
7. Conclusion 51
8. Bibliography 52
Appendix A – Survey of rate of loss of fishing tackle 56
Appendix B – Survey results of October for fishing sinkers 57
Appendix C – Survey results of October for fishing sinkers 58
Appendix D – Survey results of October for fishing lures 59
Appendix E – Survey results of November for fishing lures 60
Appendix F – Steps of making gelatin-based lures 61

Acknowledgement

First and foremost, I would like to thank my supervisors Dr. Naeem Nisar Sheikh and Dr. Alina Khasanova, who let me work independently and develop my research skills during this capstone project, but provided important feedback and offered their help and knowledge whenever needed. My gratitude also extends to my parents to whom I owe everything I am today. Next I would like to thank my friends Imane Charrafi, Nouhaila Jouibi, Zineb Guessous, and Widad Yossri who made this college journey very pleasant.

List of Figures

Figure 1: Fishing rod with the relevant fishing tackle to the study 9

Figure 2: Estimated annual weight of sinkers imported into Canada from USA, Europe and Asia in 2003 12

Figure 3: Loon found dead in Maine 17

Figure 4: Stomach of brown pelican containing ingested jig head, fishing line and hooks 17

Figure 5: Estimated current proportional use of lead vs. non lead alternatives 18

Figure 6: Molecular structure of corn starch 39

Figure 7: Gel Strength as a function of gelatin concentration at 10 C 40

List of Tables

Table 1: Causes of mortality of common loons in New Hampshire, May- Sept, 1989–2012..... 16

Table 2: Summary of loss rate of fishing sinkers according to different studies..... 18

Table 3: Estimated lost quantity of lead sinkers in Canada through imports 19

Table 4: Estimated lost quantity of lead sinkers across the globe 20

Table 5: Weighted decision matrix for fishing sinkers' alternatives 31

Table 6: Summary of rate of loss of fishing sinkers according to various studies 36

Table 7: Weighted decision matrix for fishing lures' alternatives..... 42

Table 8: Weighted decision matrix for fishing floats' alternatives 46

Abstract

Recreational fishing contributes to lead and plastic deposition in marine environments through the loss of fishing sinkers, lures and floats. The popularity and usage of lead and soft plastics by recreational fishers have increased in recent years, so does the number of anecdotal reports of lead fishing sinkers and lures found in the aquatic environments and in the digestive tract of fish and waterbird species. Overall, the presence of a multitude of harmful materials in this study, demonstrated the importance of conducting an extensive investigation to determine the actual impact resulting from the loss of recreational fishing tackle.

Results showed that more than 550 tons of lead is deposited in the Canadian aquatic environment. Furthermore, a sampling study was conducted in this project in order to measure the scale of the problem in Morocco. Results demonstrated that lead deposition is estimated to be 27 tons per year in the Moroccan Atlantic coastline. Other countries such as the US, France and Japan had quantities on a thousand tons' scale. These large quantities get lost and they continue to be accumulated overtime without being recovered. Results have also shown that the lost fishing tackle has many effects on the environment, including wildlife and water. In water, lead sinkers dissolve, accumulate in fish tissues and intoxicate the aquatic environment. Lead sinkers can also get ingested by waterbirds and the reaction between lead and stomach's acids is lethal. Moreover, soft plastic lures release the toxic substance-phthalate-in water and cause digestive problems to fish and waterbird species if ingested, this can be lethal as well.

Taking into account all of the big quantities lost and their effects, I developed safe alternatives in order to replace the currently toxic ones. These alternatives include lead sinkers coated with TiO_2 using the sol-gel, biodegradable gelatin-glycerol based lures and cork wood floats.

1. Introduction

1.1. Context & Motivation

The current manufacturing standards of fishing tackle use lead-based sinkers, and polymers-based lures and fishing floats. The equipment of the fishing tackle to be examined in this project includes: fishing float, fishing sinker and fishing lure as illustrated in the following figure:



Figure 1: Fishing rod with the relevant fishing tackle to the study

During the fishing endeavor, fishing sinkers, lures and floats can get lost in the aquatic environments due to many reasons (loose fishing line, snagging between rocks…etc.). The biggest problem with the fishing tackle is the materials that participate in its composition. The two main materials (lead and plastics) used in manufacturing the fishing tackle have noxious effects on those who handle them and on wildlife. For instance, piscivorous birds and other types of water-birds ingest fishing sinkers and lures while feeding, when they mistake them for food items or grit (stones intentionally swallowed by birds for their digestive needs). They can also be ingested when waterbirds try to eat lost baits still attached to a sinker. The ingestion of a lead sinker or lead-headed lure can expose a bird to a mortal concentration of lead. Hence, this capstone's objective is to investigate the environmental effects of the current manufactured fishing sinkers, lures and floats and to study the design of environmentally-safe ones.

1.2. Methodology

The analysis process of this capstone is to be composed of three main parts. The first part would be an investigation about fishing sinkers. Initially, the investigation will be directed toward exploring the rate of loss of fishing sinkers. This study will cover countries like Canada and the US where the participation rate in recreational fishing is high. It will also cover and for the first time an Arab country (Morocco), and other European countries. Once a rate of loss is obtained, the quantity of fishing sinkers lost would be obtained by investigating either the approximate number of anglers in a given country or by extrapolating the rate over the coastline. This first part is important to understand the gravity of this environmental issue worldwide and in a country like Morocco. Then, the study will focus on an investigation of all the possible materials that can replace lead and which can be potentially safe. The characteristics of each of these materials will be studied: density, price, melting point, ease of manufacturing, corrosion, and solubility… etc. Based on these characteristics, a weighted decision matrix will be set to decide which material is most suitable for being used in a sinker. The second and third parts would cover a study of the possible degradable materials that can substitute soft plastic-based lures and plastic-made fishing floats. For instance, soft plastic lures (SPLs) contain solvents like phthalates that can get dissolved in water and can harm mussels, clams, crustaceans…etc, with a possibility of accumulation in their bodies. Therefore, in these two last parts of the project, environmentally safe substitutes would be studied and compared against other possible alternatives using a weighted decision matrix to find the optimal alternatives.

2. Literature Review:

Before diving into the core of the project, it is necessary to document the available literature of eco-friendly fishing sinkers, lures, and floats. This literature review is of great importance as it serves to search and evaluate the work that has been done in order to improve the problem's understanding and to find any gaps in the current knowledge.

2.1. Fishing Sinkers:

Exhaustive research has been conducted to prove the harm caused by the lead sinkers. For the sake of this project, I will review more than 20 scientific papers and more than 10 additional resources, such as articles and press statements. These sources focus on Canada and the USA, because of the relevant research that has been carried out there. However, the review will cover international perspective.

In his journal article, Vernon describes the fact of continuing using lead sinkers and shots as controversial. Water birds often swallow small stones of bits of gravel that serve as "teeth" to grind and break hard food like seeds. However, fishing sinkers are usually small and resemble bits of gravel. As a result, birds can confuse between sinkers and stones while feeding. He adds that fish-eating birds like swans and geese can unintentionally consume sinkers which can be mistaken for grit or seeds [1]. According to a report of the Canadian Wildlife Service, the ingestion of fishing lead sinkers is the first most important cause of death of adult common loons reported in Canada and the United States [2]. In the United Kingdom, it was revealed that the largest reason behind the death of mute swan deaths since the 1960s was the result of the ingestion of fishing weights. This trend was altered after small-sized lead sinkers were banned in England and Wales in 1987.

No academic or scientific research has been conducted in order to prove the toxicity of the currently manufactured fishing sinkers, or to develop a design for ecologically safe ones. However, there have been some manufacturing designs to substitute lead sinkers. Nevertheless, these substitutes failed to perform well, had a very high cost or were equally if not more toxic than lead. Rattner et al. say that alternatives for lead sinkers are available, but lead sinkers are still popular among anglers because of their economical and performance advantages. None of the available lead-free alternatives offer the overall performance of lead fishing tackle with respect to gravity, malleability, ease of production, and cost [3]. In their study, Scheuhammer and Norris estimated the current proportional use of lead versus non-lead fishing sinkers in Canada and unsurprisingly found that more than 98% of the fishers still

prefer and rely on the lead sinkers. Moreover, figure 2 indicates how the imported annual sinkers continue to increase even though alternatives were present by that time. The two researchers predict that the market for non-lead fishing tackle will continue to be marginal until lead sinkers are made interdicted, unavailable or cost effective and performing alternatives come to the surface [2].

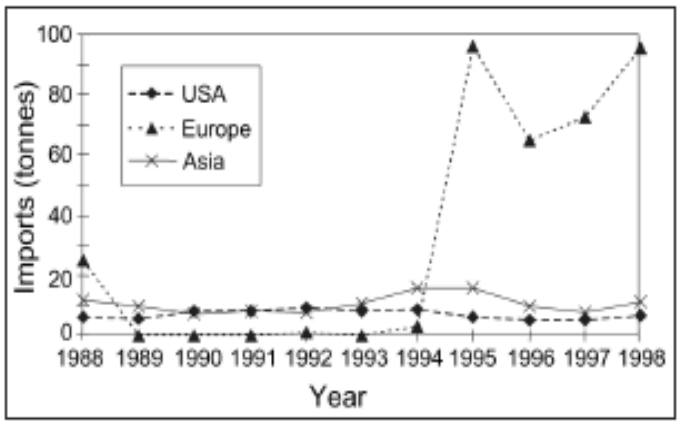


Figure 2: Estimated annual weight of sinkers imported into Canada from USA, Europe and Asia in 2003 [2].

In a study done by Jacks et al., they weighed some fishing sinkers and then placed them in two Swedish rivers with different current flows (Lagan & Dalaven). By the end of the six month-long experiment, they could recover only 75% of the fishing sinkers. The latter were weighed again and a weight loss was calculated as a loss per surface area. Fishing sinkers placed in both rivers have undergone weight loss. However, it was found that the fishing sinkers placed in River Dalaven (which has a higher flow current) had larger weight losses. The amount of lead used in the study was not significant and thus the authors did not find evident effects of lead emission from the dissolution of these sinkers. However, they believe that with a higher quantity deposited yearly in rivers, the need for the use of safe alternatives to lead sinkers is serious [4].

2.2. Fishing Lures

The most popular type of lures among recreational fishers is the flexible and soft plastics lures. Most of these lures get eventually lost in the bottom of lakes, rivers and oceans as they easily detach from the hook when bitten. These artificial lures disintegrate over time and release harmful substances such as phthalates and other petrochemicals. They also don’t degrade or decompose, even after two years of being discarded, and are being found both in nature and inside the digestive tract of fishes. It is estimated that more 25 million pounds of

lures are left in U.S. waters every year. Researcher Cory Suski, in collaboration with Steven Cooke, studied the impact of the soft lures on lake trout, smallmouth bass, and the environment. The soft plastic lures (SPLs) were found to resemble to worms or leeches that are particularly enticing to fish species and which makes them very popular among anglers [5].

Live fishing baits do replace artificial lures sometimes. However, according to a study done by Hestler, in order to catch a fish, the live bait should respect some standards. The live bait should have a suitable size and appearance acceptable to the fish. Hester takes as an example tunas and expands his study upon it. He says that for a tuna fish to be caught using live bait, this latter should possess a silvery appearance and a behavior that can induce the tuna to bite. Other requirements include that the bait must be hard enough to remain alive during capture and transport, i.e. it should not disperse when thrown into the water. Hence, the live baits should resist the mechanical damage, i.e., loss of scales and bruising. It is also important that the bait has sufficient tolerance to temperature and temperature change. For instance, if the bait is to be carried by a fishing boat from one fishing ground to another through waters of varying temperatures, it should resist this thermal change [6]. Although live baits may sound as a natural and environment friendly alternative, they were criticized by anglers a lot. These baits are most of the times cannot be found or be used again. They can also introduce diseases and invasive species to otherwise pristine waters, and can be expensive.

2.3. Fishing Floats

No literature review has been found for fishing floats. However, because fishing floats are widely used by anglers, and as it has been documented that fishing lures and sinkers get lost in the environment, it is safe to assume that they get lost and discarded as well.

3. Fishing Sinkers

3.1. Description of Fishing Sinkers

Fishing sinkers are weights used in conjunction with a baited-hook, and they are used to set the lure/bait to a desired depth. Fishing sinkers increase anchoring ability and/or casting distance and are conventionally and usually made from poured lead because of its easiness to cast. Sinkers come in various and different styles designed for different fishing methods. Sinkers, when used correctly, can present the bait in a much more effective manner. They are formed into many shapes for diverse fishing applications and the choice of the fishing sinker to be used depends on the bottom conditions and the current of the fishing place. If the bottom of the fishing area is sandy, muddy, or rocky, then the design of the sinker will differ. Hence, for the several types of sinkers, each has its proper place. The most common types of fishing sinkers include the following designs that were all retrieved from [7]:

Name and description	Picture
Bell Sinker: A sinker that is usually attached to the fishing line through a ring at top of the bell. It is useful in fishing areas with strong flow and current.	
Bank Sinker: These are ovate and long sinkers having a small hole at the top for the fishing line to thread through. This type is a good option when using river rigs.	
Egg/Barrel Sinker: As the name suggests, this type had the shape of an egg with a hole through the centre in which the fishing line is attached. The appealing feature of this type is their resistance in seawater fishing as they pass over rocks. These are also common in currents and deep water.	

Pyramid Sinker: This type has a shape of a pyramid. They are used to anchor quickly on the bottom of soft surfaces (sand or mud). This profile allows them sink quickly and resist fast currents.	
Split Shot Sinker: It is a small, round and spherical soft lead weight with a narrow cut along its diameter through which fishing line is threaded. Split shot sinkers can easily get off and on the line as it is crimped onto the line. This feature is cherished by anglers as extra little weight can be easily added when needed.	
Bullet Weight Sinker: This type of sinkers is shaped like bullets with a hole through the middle where the line is threatened. Bullet sinkers work well when used in front of soft plastic lures and when fishing for bass.	

3.2. Effects of Lead Fishing Sinkers on Wildlife

Lead (Pb) is a natural heavy metal present in the environment. It is not important or essential in biological systems as it plays no functional role in the cellular or molecular levels of organization. Lead has been one of the most highly studied metals for its toxicity that is evoked in multiple organ systems. Lead exposure can have serious consequences on health, which include lead induced anemia and neurological impairments. Being exposed to lead can also cause hypertension, reproductive/endocrine system toxicity and "immunosuppression" characterized by increased susceptibility or reduced resistance to bacterial and viral diseases. However, for centuries lead has been widely used in cosmetic products, paint, batteries, and in ammunition and fishing tackle [3]. Even though lead is naturally occurring, it is regarded as a severe and direct threat to wildlife. For instance, large amounts of lead fishing sinkers are produced and sold annually and most of these sinkers, if not all, finish in our aquatic systems.

Under some conditions, lead sinkers can be relatively stable in water. However, for an aquatic system that is acidic, lead sinkers will dissolve, precipitate and release some complex species with organic or inorganic matter. Once in water, if lead dissolution is high and its concentration in water increases, it will be absorbed by fishes mainly into their tissues. These latter can be consumed by humans and can have the health consequences already mentioned [4].

The hazards of lead exposure have been studied throughout the history. However, the recognition of the dangers related to ingesting fishing sinkers are relatively recent. Wildlife lead toxicity exposure has been traditionally linked to ingesting lead shots from hunting or lead arsenate pesticide. It is in late 1970 that the hazards of lead sinkers have finally become recognized when the population of mute swans (*Cygnus olor*) sharply decreased in Great Britain. As explained in the literature review, water birds swallow fishing sinkers that are generally less that 50g and smaller than 2 cm. Lead fishing sinkers can be mistaken for bits of gravel or food used in the gizzard (a digestive organ exclusive to birds) to grind up food. In a research article by Grade et al., a study was conducted in order to investigate the population-level effects of lead fishing sinkers on common loons. As the table below shows, almost 49% of the cause of death of common loon population in New Hampshire was due to ingesting lead fishing sinkers [8].

Table 1: Causes of mortality of common loons in New Hampshire, May- Sept, 1989–2012 [8].

Cause of death	No.	Percentage %
Lead fishing tackle	123	48.6
Unknown	35	13.8
Trauma, unknown	21	8.3
Aspergillosis	14	5.5
Trauma, boat	12	4.7
Monofilament entanglement	10	4.0
Trauma, conspecific	9	3.6
Lead, unknown object	8	3.2
Non-lead fishing gear	8	3.2
Gunshot	3	1.2
Other	10	4.0
Total	253	100

Waterfowl are the most vulnerable species to lead because of its high concentration and availability in shallow wetlands. Prior to the ban of lead fishing sinkers in some national parks in the US, mortality of waterfowl ranged from 1.6 million to 3.9 million birds per year. After the ban, the number of waterfowl who ingested lead dropped by 50 percent, this saved about 1.4 million ducks per year. Furthermore, the ingestion of lead fishing sinkers has negative impacts for three months. In most cases the reaction between lead and acids inside the stomach can kill waterfowl. And, if mortality does not occur, poisoned waterfowl will exhibit a depressed activity with high risks of harvest or predation [9]. The figures below show waterfowl found dead in different lakes due to lead ingestion.

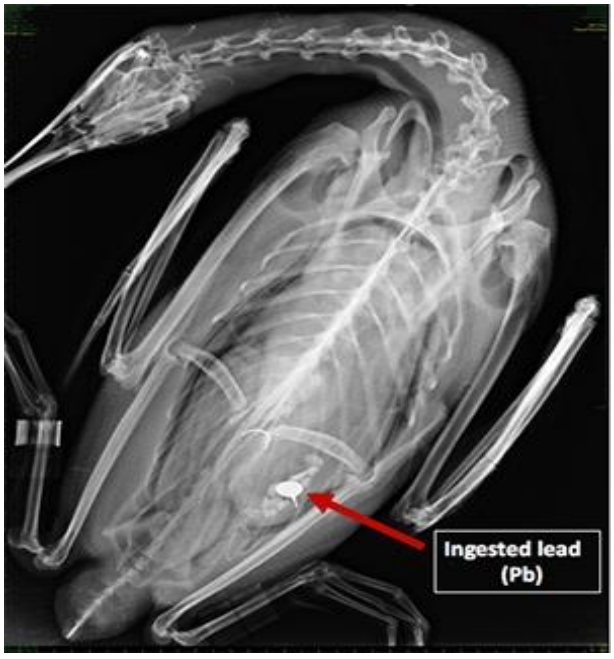


Figure 3: Loon found dead in Maine [9]



Figure 4: Stomach of brown pelican containing ingested jig head, fishing line and hooks [9]

3.3. Fishing Sinkers Loss Rate

Lead has been linked to fishing activities for so long. Various forms of lead sinkers, lures, jigs and even nets are introduced in the aquatic environment while fishing. They accidentally can be lost and dropped into water if the line becomes entangled, get cut or broken. However, there is no precise information about how much lead fishing sinkers is being produced, purchased and subsequently lost and entering the environment. Yet, estimates have been and can be made. For instance, the European Commission Enterprise has estimated in 2004 that the amount of fishing tackle sold each year is between 2,000 and 6,000 tons for Europe only [2].

A variety of factors influence the loss rate of fishing sinkers and the results of the rate vary from one study to another. The factors that influence the loss rates include:

- The type of the fishing activity.
- The location of the fishing activity.
- The time of year or weather conditions.
- The expertise and skills of the recreational fisher.

The different rates of loss of fishing sinkers of many studies are summarized in table 2.

Table 2: Summary of loss rate of fishing sinkers according to different studies

Study	**Loss Rate**	**Location Details**
[4]	0.18 sinkers/ m^2	UK
[4]	Up to 190 sinkers/m^2	Europe
[4]	1 tonne total lead lost per 6.000 anglers/year	Minnesota Lakes
[4]	0.45 sinkers/m^2	US
[11]	0.049 sinkers/m^2	Spain
[11]	0.076 sinkers/m^2	Spain
[11]	0.012 sinkers/m^2	Spain

3.4. Estimated Lost Fishing Sinkers

3.4.1. Example of Canada

According to the study conducted by Scheuhammer et al., Canadians spent more than USD 2.5 billion (an average of USD 533 per angler) on fishing goods and services in recreational fishing in 1995. This number shows the passion Canadians have for fishing and which did not cease to grow over time. In 1997, some regulations were initiated in order to regulate the use of fishing lead in Canadian National Parks and National Wildlife Areas, those regulations are believed to have affected only a small portion of Canadian anglers. Manufacturers have also come up with alternatives (tungsten, tin, nickel…etc.) that can mitigate the problem. However, these efforts did not have a great impact as the usage of lead sinkers has decreased by 1% only as the figure shows [2]:

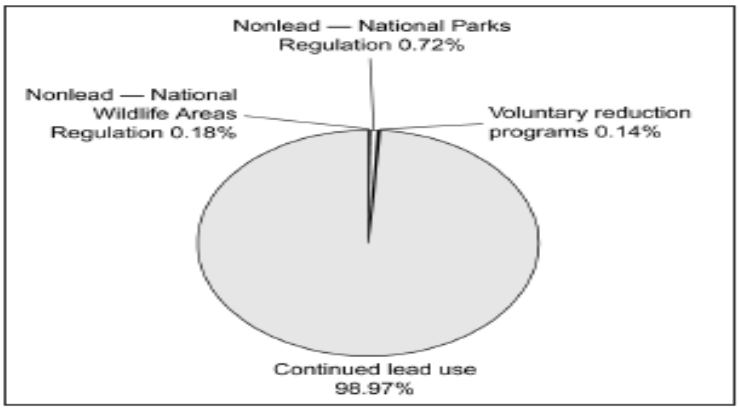


Figure 5: Estimated current proportional use of lead vs. non lead alternatives [2]

Using Scheuhammer's approach we can also get an approximation of lost sinkers in a country assuming that the quantities of sinkers purchased are to replace those lost while fishing [2].

As there are no official data about the quantity of fishing sinkers imported and sold, the Canadian Minister of Environment Change had recourse to sinkers imports per year (C$) and the average price of lead (C$/ton) in order to find the quantity imported [10]. As can be seen from the following table, the quantity of lead sinkers imports had been increasing between 2011 and 2015:

Table 3: Estimated lost quantity of lead sinkers in Canada through imports [10]

Year	**2011**	**2012**	**2013**	**2014**	**2015**	**Avg. of 5 years**
Lead Sinkers Imports per year (C$)	444,160	415,336	729,915	849,901	835,130	654,888
Avg. price of lead (C$/ton)	2,369	2,060	2,202	2,313	2,282	2,246
Total (Tons)	187	202	331	367	366	291

The values estimated in the table are based on imports of fishing sinkers only. It should be noted that there are local Canadian manufacturers of lead fishing sinkers and so these numbers do not reflect the complete picture. Using another approach suggested by the Canadian Minister of Environment Change in order to come up with a better estimate, a survey was run where more than 80.000 anglers were asked about the number of lost sinkers per year. The survey results showed that each Canadian angler loses between 11 and 15 lead fishing sinker per year. Considering that Canada has 3.3 million anglers and that the average weight of a fishing sinker is 11 g, the total quantity lost in the Canadian waters would equate to 545 tons/year [10].

3.4.2. Across the Globe

Table 4: Estimated lost quantity of lead sinkers across the globe

Country	Basin	Population (Million)	Participation Rate	No. of Fishers (Million)	Quant. of Lead[1] (Tons)	Year of Estimate	Reference
Albania	MED	2.896	2.7%	0.078	10.33	2016	[11]
Belgium	AT	11.204	0.22%	0.024	3.168	2016	[11]
Cyprus	MED	0.858	2.7%	0.023	3.05	2016	[11]
Croatia	MED	4.247	2.7%	0.115	15.18	2016	[11]
Bulgaria	MED	7.246	2.7%	0.196	25.87	2016	[11]
Denmark	AT	5.7	6.77%	0.386	50.95	2016	[11]
Estonia	AT	1.313	11.3%	0.149*	19.67	2015	[13]
Finland	AT	5.45	27.5%	1.5*	198	2014	[13]
France	AT & MED	63	5.1%	2.5*	330	2013	[14]
Germany	AT	82.5	1.8%	1.5*	198	2008	[12]
Iceland	AT	0.326	31.6%	0.103	13.6	2016	[11]
Ireland	AT	4.6	1.67%	0.077	10.16	2016	[11]
Italy	MED	60	2%	1.2	158.4	2016	[11]
Latvia	AT	1.95	6.15%	0.120*	15.84	2017	[13]
Lithuania	AT	3.56	28.1	1*	132	2007	[12]
Netherlands	AT	17	11%	1.87*	246.84	2005	[15]
Norway	AT	5.108	33%	1.285	212	2016	[11]
Poland	AT	38	5.2%	2*	264	2014	[13]
Portugal	AT	10.427	1.7%	0.175	23.1	2016	[11]
Spain	AT & MED	46.49	0.7%	0.298	39.34	2016	[11]
Sweden	AT	9.85	14.2%	1.4*	184.8	2016	[13]
UK	AT	64.308	1.79	1.150	151.8	2016	[11]
USA	AT	327	10.1%	33*	4,356	2017	[16]
Japan	PA	127.77	8.9%	11.43	1,508	2007	[16]
Australia	PA & IN	24.6	12.2%	3	396	2017	[17]

*Indicates that the No. of fishers include anglers in freshwater.

[1] The quantities were found by assuming a rate of loss of 12 lead sinkers/angler and an average weight of 11 g/sinker.

3.4.3. Sampling study in Morocco

Throughout this project, scarcity of statistics about the recreational fishers around the globe was very noticeable. Just like for many countries outside Europe and North America, no data about the activities of recreational fishers in Morocco was found. As there was no data about the rate of loss of fishing sinkers in Morocco or the number of Moroccan recreational fishers, a sampling study was necessary in order to get a scale of the problem in the Moroccan context. The study was conducted by making a survey (Appendix A) and asking anglers on-site over 20 km of the Atlantic coastline of Casablanca (Al Hank, Tamaris, and Dar Bouazza neighborhoods) and Rabat (Mellah neighborhood). While gathering data, the 20 km were divided into smaller sections of study of 1 km. In other words, the anglers that were present in each 1 km of the studied area were interviewed. Throughout these 20 km, almost 60 anglers were interviewed as there were almost 3 anglers per 1 km studied. This survey was held over two months, October and November 2018, and the results of the surveys for sinkers are summarized in Appendices B and C. The average number of lead fishing sinkers of the 20 samples were added to each other and divided by 20 in order to get an average of lost sinkers per one kilometer. According to the results of the first survey (which took place in October), the rate of loss of lead fishing sinkers during this period is 3.3 sinkers/km/day. In November the fishing sinker loss rate was slightly higher which can be explained by the harsher weather conditions during this time period (windier weather compared to October). According to the results of November's survey, the rate of loss of lead sinkers would be 3.8 sinkers/km/day. In order to find an approximate loss rate, the average of the two rates over the two-month long period was taken which equals 3.55 sinkers/km/day.

As the rate of loss found was 3.55 sinkers/km/day, and assuming that the rate of loss would not differ much along the entire Atlantic coastline, extrapolation can be used in order to find the quantity of lost fishing sinkers per year. The Atlantic coastline distance from Tangier to Guelmim is about 1835 km. Thus, for a rate of loss of 3.55 sinker/km/day, a distance of 1835km, 365 days in a year, and an average weight of 11g per sinker, the quantity lost per year would equate to **26.15** tons of lead each year.

3.4.4. Projection over the next decade

The noxious effects of lead fishing sinkers have been known for a while now but the market for it has remained largely unchanged. In fact, according to stockholders, the market is believed to be steady, stagnant and dominated by lead products. Even though some regulations have taken place in order to ban lead fishing sinkers in national parks, the number

of anglers affected by these bans is very small. It should also be noted that the number of anglers is not expected to change significantly over the next decade as it has not changed much over the previous one. Thus, with these numbers of anglers and with their steady demand for lead tackle products, the quantity of lead lost in our aquatic environments is not expected to decrease over the next 10 years [10].

Moreover, manufacturers and fishing tackle shops assert that even though alternatives are available, the market for these products remains very marginal. The main reason behind not buying the available alternatives is their higher cost, and lower performance compared to lead. Anglers are reluctant to consider the alternatives as lead versions are available at cheaper prices. Therefore the situation is expected to remain unchanged over the next decade as long as there are no additional widespread regulatory measures applied to lead sinkers. Since in Canada almost 545 tons of lead sinkers are lost to the aquatic environment each year, and assuming that this situation is not expected to change, an estimated total of 5,450 tons of lead can be expected to accumulate in the Canadian environment over the next decade.

By analogy, if 26.15 tons of lead fishing sinkers is lost in the Atlantic coastline of Morocco each year, and with no usage of other alternatives by fishermen, no regulations, and no recovery, the situation is expected to be unchanged over the next decade as well. The same goes for the European countries mentioned above, the estimated total quantity of lead sinkers lost is calculated for the 22 European countries is 1.334 tons per year. Again, if this number is projected over the next decade, the quantity of lead sinkers present in part of the European waters would be more than 13.340 tons. With the accumulation of these numbers, and with no measures taken to solve this problem, recreational will be causing more harm than pleasure.

3.5. Alternatives study

3.5.1. Possible Alternatives

3.5.1.1. Tungsten

Tungsten (W) is a hard metal with a shiny and silvery appearance. Tungsten resists both oxidation and attacks by alkalis and acids. It is extracted from two main types of minerals, Wolframite and Scheelite and is represented by W. Its atomic number is 74 and it is part of the transition metal category. China is the world's largest producer of Tungsten with a world supply of 80%. Tungsten has the ability to keep its shape at high temperatures and it has a very high tolerance to intense heat. Its filaments are used in a variety of applications: floodlights, microwaves, x-ray tubes, electrical furnaces…etc. The world production of Tungsten is approximately 40.000 tons per year while the reserves are expected to be 5 million tons. Tungsten is becoming popular among anglers because of its smaller size and denser property. Tungsten also produces more sound under water compared to lead [19].
Tungsten properties:

- **Density**: 19.3 g/cm^3[19]
- **Melting Point**: 3370 °C [19]
- **Price**: 44$/kg [20]
- **Solubility**: Tungsten is insoluble in water but can be slightly soluble in nitric and sulphuric acids [19].
- **Resistance to Corrosion**: Tungsten has an excellent corrosion resistance. It has a high resistance to oxygen, acids and alkalis. It is hardly attacked, but can be slightly attacked by some mineral acids [19].
- **Toxicity**: This product is not expected to be hazardous for the environment. However, no specific eco-toxicity data is available for this metal [19].

3.5.1.2. Tin

Tin (Sn) is a metal characterized by being soft with a silvery-white appearance. Tin is most often produced from the mineral "cassiterite", which is made-up of about 80% tin. It has the atomic number of 50 and its chemical symbol is Sn. Tin is known for its malleability and ductility. It is malleable at ordinary temperatures but weak and brittle when cooled. It is also the 49th most abundant metal in the earth's crust. Currently, China and Indonesia are the

world's largest producers of tin. Tin does not have any known biological role in humans, but it can be essential for some species. Tin is very light and easy to melt and it has many uses [18].

- **Density**: 7.3 g/cm^3 [18]
- **Melting Point**: 232°C [18]
- **Price**: 19$/kg [20]
- **Solubility**: Elementary Tin is not soluble in water under normal conditions (Temperature = 20^{o}C and pressure = 1 bar) [18]
- **Resistance to Corrosion**: Tin has a very high resistance to corrosion. Corrosion from distilled, sea and soft tap water does not occur in tin. However, corrosion can happen if it comes in contact with very strong acids, alkalis and acid salts. It is usually used to coat other metals in order to prevent corrosion (i.e. used to polish cans) [21].
- **Toxicity**: Tin is not toxic, but its organo-tin compounds can be poisonous and so it must be handled with care. Plants can also easily absorb tin [18].

3.5.1.3. Brass

Brass is an alloy of zinc and copper with copper the main component. The color of brass can go from reddish brown to a light silvery yellow depending on the amount of zinc contained- the greater amount of zinc the lighter the color. With different proportions of zinc and bronze, the properties of brass can vary creating various brasses with varying properties. Because of the variation in this alloy, the properties of brass are not universal. However, it is widely agreed that brasses are easily formed (i.e. malleability) with a high strength retained after forming. All brasses are also known to be ductile- brasses with higher zinc variations are less ductile compared to the ones with lower zinc content. Brass is also harder and stronger than copper and is a good conductor of heat. The attractive feature about brass is that it is a poor breeding ground for bacteria (i.e. antimicrobial properties). As a result it is an ideal material in medical applications and for bathroom fixtures and doorknobs [21].

- **Density**: 7.7-9 g/cm^3 [21]
- **Melting Point**: 870-1095 °C [21]
- **Price**: 4.6$/kg [20]
- **Solubility**: Brass is not soluble in water [22].
- **Resistance to Corrosion**: Brass is not very resistant to corrosion especially when it is in contact with water. Because Brass contains an important amount of zinc, it is very susceptible to "dezincification"- the corrosion of zinc. When zinc corrodes in the alloy, it leaves behind it a weak shell consisting of the remaining copper [22].
- **Toxicity**: According to a study done in Edgewood research, development & engineering center by Haley and Kurnas, it was found that the toxicity of brass materials is ranked high having a half maximal effective concentration EC_{50} below 1mg/L for dalphnia and algae (due to Zinc) [22].

3.5.1.4. Copper

Copper (Cu) is a reddish-gold metal and an essential biological element. It has the element number 29 in the Periodic Table of Elements. Copper has a high electrical and thermal conductivity and is widely used in electrical applications, and building construction. Copper is also known to be one of the most ductile metals. Copper does not occur naturally but is extracted from mineral sources such as chalcopyrite and bornite. It is obtained from these ores and minerals by means of leaching, smelting and electrolysis. Chile, Peru and China are the biggest copper-producers in the world [24].

- **Density**: 8.96 g/cm^3 [24].
- **Melting Point**: 1083°C [24].
- **Price**: 6.7$/kg [20]
- **Solubility**: Since copper lies below hydrogen in the electromotive series, it is not soluble in acids with the evolution of hydrogen. Yet, it will react with oxidizing acids (i.e., nitric acid and concentrated sulfuric acid). Copper can resist the action of the atmosphere and seawater [23].

- **Resistance to Corrosion**: When copper is exposed to the atmosphere, it oxidizes. The oxidization causes the bright copper surfaces to tarnish. Over time, the tarnish changes from dark brown to black, and finally to green [23].
- **Toxicity**: In a study done by Besser and Leib, brook trout and fathead minnows were found to be highly sensitive to copper. As a result, significant reductions in the growth of these species occurred at concentrations less than 10µg/L [25]. In laboratory tests, it was indicated that copper is even more toxic to aquatic species compared to lead.

3.5.1.5. Zinc

Zinc (Zn) is an abundant element found in earth's crust. At room temperature, zinc is brittle and has a color between white and blue. Zinc is weak and a low tensile strength and this is why it is not used in load-bearing applications. It has also a low toughness and is generally brittle. Zinc has also a moderate conductivity for a metal, but it has strong electrochemical properties and it serves in the galvanizing process and alkaline batteries [26]. Zinc is the 4th most widely used metal in the world. It has strong resistance to corrosion and it bonds well with other metals.

- **Density**: 7.1 g/cm^3 [26].
- **Melting Point**: 420°C [26].
- **Price**: 3.37$/kg [20].
- **Solubility**: Zinc is insoluble in water. However, solubility increases with increasing acidity, temperature, and chlorine concentration and decreasing hardness [26].
- **Resistance to Corrosion**: Zinc has great resistance to corrosion and it is widely used to coat other metals. However, in seawater it shows lower resistance as it forms an oxide layer when corroded [27].
- **Toxicity**: Tests have demonstrated that dissolved zinc is highly toxic to birds, fishes and aquatic plants. For instance, zinc is very toxic to amphipods, less toxic to fathead minnows, and least toxic to brook trout [25].

3.5.1.6. Bismuth

Bismuth (Bi) is a heavy metal with a purple-silver appearance. It is the element the most naturally diamagnetic (it repels north and south). Among metals, bismuth has the lowest values for thermal conductivity and the highest electrical resistance. Bismuth is also brittle and is usually combined with other materials to strengthen it. It has also a low melting point and unique thermal expansion properties. Bismuth is also a non-toxic metal. Being both non-toxic and stable, it became an important substitute for lead. The major bismuth producers are China, Mexico and Belgium [28].

- **Density**: 9.78 g/cm^3 [28]
- **Melting Point**: 521°C [28]
- **Price**: 40$/kg [20]
- **Solubility**: Bismuth is stable and does not dissolve in water. However, it dissolves in concentrated nitric air [28].
- **Resistance to Corrosion**: Bismuth is fairly resistant to corrosion in air and seawater [28].
- **Toxicity**: A study was conducted to check the toxicity of Bismuth in the marine environment by exposing three different species of "macroalga" to increasing concentrations of bismuth. The results showed that the phyto-toxicity (toxicity for plants) of bismuth is very low [29].

3.5.1.7. Nickel

Nickel (Ni) is a naturally occurring, strong, silvery-white metal. It occurs mainly in sulphide and arsenic ores and is the 5th most abundant metal on earth. Nickel is used in more than 300.000 different products for marine, transport, aerospace and other applications and is thus one of the widely used metals. It is known for its malleability and ductility.

- **Density**: 8.9 g/cm^3 [30]
- **Melting Point**: 1455°C [30]
- **Price**: 10.6$/kg [20]
- **Solubility**: Nickel is insoluble in cold/hot water, insoluble in dilute nitric acid and slightly soluble in hydrochloric acid and sulfuric acid [30].

- **Resistance to Corrosion**: Nickel is relatively resistant to corrosion [30].
- **Toxicity**: Nickel is not toxic, but soluble nickel sulfate is found to be very toxic [30].

3.5.1.8. Lead Coated with Titanium Dioxide (TiO_2)

Titanium dioxide (TiO_2), also called titania, is a naturally occurring oxide of titanium, an odorless, opaque, absorbent, and white powder. Titanium dioxide exists in a number of crystalline forms, with rutile and anatase being the most important ones. Titanium dioxide is widely used for bleaching and opacifying vitreous enamels (the process of fusing a thin film layer of particles to a metal) in order to make them hard, white, opaque, hard to scratch and to increase their acid resistance. Titanium dioxide contains nano-sized particles with a size of almost 21 nm, and these particles have a hydrophilic character. In other words, TiO_2 interacts well with water because hydroxyl groups coat its surface and these latter can form hydrogen bonds with water molecules. In the fine powder form, TiO_2 particles with a diameter of approximately 21 nm join together and form aggregates. When coating using TiO_2 pigment, particles are applied on a nano-scale [31].

- **Density of TiO_2:** About 4 g/cm^3
- **Surface Area of TiO_2:** Titanium dioxide has an incredible surface area which is between 25-50 m^2/g.
- **Price of TiO_2:** $39/25g
- **Acids Resistance/solubility:** Titanium dioxide is used in order to coat vitreous enamels to prevent them from scratching, corrosion and acids.
- **Toxicity of particles:** No relevant toxicological and human exposure data about TiO_2 are known. However, the current research journals suggest that titanium dioxide has a low acute toxicity. In fact, the photo-catalytic activity of TiO_2 results in thin coatings of the material as it has antimicrobial characteristics and it is widely used in medicine applications and apparatus and even cosmetic products [31].

In a research journal written by Curkovic et al., they investigated how AISI 304 stainless steel can be protected against corrosion by applying TiO_2 films. During this study, TiO_2 films were deposited on the 304 stainless steel by sol-gel process, dip coating process. Sol-gel method is a process known as chemical solution deposition. Sol gel method can be applied to metals through different techniques, mainly spin coating, dip coating, and spraying.

Dip coating has been proven to be the most efficient techniques for heavy metals (such a lead). This method consists of the polymerization of molecular precursors in solution in order to obtain glassy (using ceramics such as ZrO_2, TiO_2, SiO_2) coated materials without heating the raw material up to the melting point. The main appealing features of sol-gel are: low equipment cost, low processing temperature, cost effectiveness (compared to other methods such as chemical vapor deposition CVD, plasma spraying, or physical vapor deposition PVD), environment friendliness, and its ability to produce materials with high purity and homogeneity in the surface of the coat. All of these features make the sol-gel a very attractive and appropriate technology for applying thin, nano-structured films.

To prepare the TiO_2 sol-gel, the following components were used:

- **Precursor**: titanium (IV) isopropoxide ($Ti(C_3H_5O_{12})_4$)-TIP
- **Solvent**: i-propanol (C_3H_7OH)-POH
- **Catalyst**: nitric acid (HNO_3) 0.5 M
- **Chelating agent**: acetylacetone ($CH_3(CO)CH_2(CO)CH_3$)-AcAc

The stainless steel samples were dipped into this gel in order to coat them with thin films of TiO_2. Titanium dioxide nano-structured coatings are interesting because they provide effective protection to metals and high resistance to oxidation and wear, a good chemical stability and good photo-electrochemical and antibacterial properties. In the paper of Curkovic et al., the corrosion resistance of steel was examined after applying TiO_2 thin films in neutral (NaCl solution) milieu and in an acid chloride milieu. In order to assess the behavior of TiO_2 coated steel in the two environments, electrochemical impedance spectroscopy (an analysis method used to the surface of a system) and polarization measurements. The results of the study were as follow:

- In a 3wt.% NaCl solution (which is a milieu similar to marine environments), the unprotected steel sample had a negative corrosion potential while the coated steel sample exhibited an increasing corrosion resistance with increasing number of layers of sol-gel TiO_2 films. The highest resistance was obtained for a steel sample coated with three layers of TiO_2.
- In a 0.5 M HCl which a very strong acid that fully dissolves (pH= 1.3), it was observed that TiO_2 improved the resistance of steel coated samples as they displayed high resistance to corrosion compared to uncoated samples [32].

3.6. Weighted Decision Matrix

3.6.1. Criteria of the Weighted Decision Matrix

After discussing the characteristics of the possible alternatives that can replace lead sinkers, a weighted decision matrix is necessary in order to evaluate and prioritize the options. The weights assigned in the decision matrix will range from 1 to 5, with 5 is the most desirable and 1 the least. Among the criteria that are considered important in the decision making of the material to be chosen, there are:

- **Price:** the price is a very important factor when coming up with a substitute. As have already been discussed, alternatives such as tungsten and tin fishing sinkers are available in fishing tackle shops, but very few anglers buy them (1% of Canadian anglers). Thus, price is a relevant factor that anglers take into account when choosing their fishing sinker and it will have a weight of 5.
- **Density:** one of the main reasons lead products in fishing tackle are still very popular is the fact that lead has a very good density. Anglers prefer smaller and denser fishing sinkers. As this is a determinant factor for anglers, density criterion will have a weight of 5.
- **Melting point:** the melting point is a factor that should be taken into account as it determines that total cost of manufacturing the fishing sinker and the ease of manufacturing involved. This criterion will have a weight of 4.
- **Corrosion**: corrosion is a relevant factor to look at as it is important that the fishing sinker does not corrode in water and/or in air. If the material of the sinker corrodes, anglers will most probably not buy it as it will not be durable in their fishing tackle box. This criterion will have a weight of 4.
- **Solubility**: solubility refers to the ability of a metal to go into solution (dissolve). Loosing fishing sinkers seems to be inevitable and with no recovery measures their lost quantity is growing. This is why the material should be stable in the aquatic environments with no potential possibility of releasing toxic substances. Thus, this factor will have a weight of 4, as it indirectly goes in conjunction with toxicity.
- **Toxicity:** the main objective of this project is to solve or mitigate the environmental effects of fishing tackle on wildlife and aquatic environments. In order to realize this objective, the material suggested should be safe in both the neutral marine environment and acidic in case it is ingested by waterfowl. As this is a very relevant factor to the study, it will have a weight of 5.

3.6.2. Discussion of the Weighted Decision Matrix

Table 5: Weighted decision matrix for fishing sinkers' alternatives

Material	Price (5)	Density (5)	Melting Point (4)	Corrosion (4)	Solubility (4)	Toxicity (5)	Total
Tungsten	1	5	1	5	4	4	**90**
Bismuth	1	3	3	3	4	4	**80**
Tin	2	2	4	5	4	4	**92**
Nickel	3	3	2	4	4	4	**90**
Brass	4	2	2	3	3	4	**64**
Copper	3	2	2	2	2	2	**59**
Zinc	4	2	3	2	2	1	**63**
Lead	5	4	5	4	3	1	**98**
Lead coated w/ TiO_2	5	4	5	5	5	4	**125**

As can be retrieved from the table, tungsten has a very good density (it is denser than lead), it is not toxic, it has also good corrosion resistance and it is stable in water and acids. However, it is very expensive and it has a very high melting point which will increase the overall price of its manufacturing and casting. Bismuth, nickel and tin have almost the same profile, they are not corrosive, and are stable in water and acidic environments. However, their density is not high and their price is more expensive than lead. As per copper and zinc, they provide a cost effective alternative. However, they are both corrosive materials, they are also unstable and soluble in aquatic environments. It can be concluded that even though alternatives are present and available in the market, their prices and performance do not encourage anglers to give up on lead. Lead combines all the good features looked for (density and cheap price) this is why lead products will remain a top choice for anglers. For this particular reason, plating or coating lead is the possible solution that can solve the dilemma.

As discussed in the study of Curkovic et al., sol-gel method can be a very efficient method to apply homogenous and strong thin films at the surface of metals and heavy ones. Using this research journal, it can be safely assumed that lead sinkers can undergo the same process in order to increase their corrosion resistance and mitigate lead emission in aquatic environment. Using the technique of sol-gel will also ensure a solid and homogenous film covering the sinkers so that they can resist acids even in the long run. In fact, according to a

research article by Beasely et al., it was found that the pH inside the stomach tract of water birds such as suliformes is within the range of 3.0 and 3.5. If the stainless steel sample could resist acids of higher acidity (1.5), it can be assumed that the TiO_2 coated lead sinkers will resist acids inside the digestive systems of birds [32].

It should be also noted that fishing sinkers should be prepared for the process of sol-gel by removing all the oxides that are built up on their surface and which cannot be seen. These oxides should be removed so that the bonding between TiO_2 and lead can be strong and durable –the lead's oxides can be removed using acid washing.

3.6.3. Cost analysis of the chosen alternative

To coat the fishing sinkers with TiO_2, its specific surface area and price should be documented.

- **Specific Surface Area:** $25m^2/g$
- **Price**: $39/25g or $1.56/g (US Research Nano)
- **Average surface area of a fishing sinker:** $12.56cm^2 = 0.001256m^2$

Therefore, if each gram of TiO_2 costs $1.56 and 1 gram can coat $25m^2$, then to coat a surface area of $0.001256m^2$, this will require $0.002+labour costs. However, as already mentioned, to get a very strong coating that can resist high acidity; the material should be coated with 3 layers. Thus, the cost to coat one lead fishing sinker with TiO_2 is $0.006+labour costs.

3. Fishing Lures

3.1. Description of lures

A fishing lure is what is put at the end of the fishing line and which determines the success of the fishing endeavor. Unlike live baits, artificial fishing lures might be used multiples times and they are designed to perform the following objectives:

- Imitate live baits such as small fishes, worms, and minnows.
- Attract fishes thanks to their horizontal and/or vertical motion, color and size.

Fishing lures design changes with the targeted species to be captured. For instance, panfish and trout require different fishing lures than pelagic fish. The most common lures types are the following (all the pictures were taken from [33]):

Spinnerbaits: This type refers to the fishing lures with one or more spinner blades often made of thin metal. The spinnerbait is designed such that its motion is similar to a propeller. Because the oval shaped blade spins, it creates different degrees of flash and vibration mimicking small fishes or any other preys. Additionally, the blades of spinnerbaits usually are coated to catch light making it more attractive to fishes. This design is essentially made to catch species like brass and pike as they are attracted by the vibration and brightness of spinnerbaits [33].



Crankbaits: Crankbait lures are divided into two groups, lipped and lipless. For the lipped crankbaits, they have a metal or plastic diving lip that bulges from the head of the lure. This protruded lip made of either metal or plastic is the feature which makes the crankbait to dive and causes the wiggling action. This diving lip varies in size, shape and angle according to the style of the crankbait. The second group is the lipless crankbait, which as the name suggests, does not have a diving lip. Their tow point is always on the top of the lure instead of the nose or underneath. This



imbalance caused by the internal weight and the lure design is what causes the lure to run at the desired depths [33].

Spoons: This type is the oldest of fishing lures. A typical spoon lure is made of an oblong piece of metal or PVC to which a treble hook is hang at one end and another loop or grommet hang at the other end. Spoon lures are characterized by a colorful pattern in one side and a reflective metallic surface on the other (spoon lures that are reflective on both sides exist). This shape enables the lure to "wobble" when pulled through water- this movement is what attracts fishes [33].



Jigs: This type of lures consists of a lead sinker with a molded hook and usually covered with a soft body (soft plastic) to attract fishes. The design of jigs creates a changeable and vertical motion, as opposed to spinner baits which move in a horizontal motion. The jigs are to pierce a fish in another part other than its mouth and it is very versatile. It can be used in fresh or sea water and it can attract many species [33].



Buzzbaits: This type of lures is made of a metal-wire frame that brings all the other components together. The wire is shaped into a J and contains a blade at the end of it and small "wings" that "catch" water as the lure is pulled. Just like the spinnerbait, the water forces to spin and as a result, the lure is lifted up onto the surface and creates a "gurgling" and "splashy" action. This action or vibration attracts fishes unable to see the lure [34].



These lures, when not made from a metal, are made from a polymer and they are soft plastic lures. Fishing lures or Soft Plastic Lures (SPLs) are made out of polyvinyl chloride (PVC) a thermoplastic polymer and plasticizers. PVC is known for its versatility which makes out of it extensively used in many industries: healthcare, packaging, electrical/electronic applications and in fishing. Unlike the other thermoplastics, PVC does not heavily rely on

crude oil. Without the addition of some additives, pure PVC is brittle and white colored. As part of the manufacturing process, PVC is made in two varieties, one is rigid (un-plasticized polymer) and one is flexible [35]. Some of the properties of PVC are:

- **Density**: compared to the other plastics, PVC is pretty dense (1.38 g/cm^3).
- **Strength**: the rigid form of PVC has a pretty high tensile (2.6 N/mm^2) and yield strength.
- **Economics**: PVC is cheap and available as it does not heavily depend on crude oil.
- **Hardness**: rigid PVC is very hard.
- **Chemical Resistance**: PVC has a very good chemical resistance to dilute acids and alkalis [36].

Flexible PVC is made by adding plasticizers which are colorless and odorless esters. Plasticizers are usually added to materials (plastic or elastomer) to make them softer, more flexible and pliable. They are bulky organic molecules and the role of plasticizers molecules is to intersperse between PVC chains, to beak the PVC crystallinity and to internally lubricate the polymer blend. The more plasticizer added the softer and more flexible the plastic would be. In PVC, plasticizers are added in more than 15 parts per hundred PVC resins (phr) to make the PVC flexible [36]. The widely used kind of plasticizers is phthalates, an organic substance used to make plastics flexible and hard to break.

3.2. Lost fishing lures in wildlife

Soft Plastic Lures (SPLs) used by recreational fishers get usually lost or discarded in the environment. Losing fishing lures can happen in the following cases:

- The fishing line breaks when wrongly casting the line.
- The fishing lure snags between rocks.

With the increasing number of recreational anglers, SPLs have increased in the environment as well. Around the world, artificial fishing lures or SPLs are used to replace live baits which can introduce parasites. Even though SPLs are durable and can be used multiple times, they unfortunately get lost in the environment. In fact, SPLs are being found in aquatic environments and even in the digestive systems of fish species and water birds.

3.2.1. Rate of loss of fishing lures

In a growing number of reports related to fishing tackle loss the following rates were suggested for fishing lures:

Table 6: Summary of rate of loss of fishing lures according to various studies

Study	Lure Loss Rate	Location
[38]	0.023 lure/hour	UK
[38]	0.0127 lure/hour	Minnesota Lakes, USA
[38]	~80 lures/km/year	Charleston Lakes, CA

To quantify the weight of lures, scientists performed snorkel surveys in Charleston Lake, a lake in southeastern Canada with a rocky shoreline of 152km. The rate of loss of SPLs was found to be 80 lures per kilometer each year. Considering this rate, this would equate to an approximate total of 12.160 lures lost in this lake. And, assuming an average weight of 8.75g per lure, this would translate to approximately 106kg of SPLs deposited into Charleston Lake each year [38].

3.2.2. Sampling study in Morocco

As has been discussed in p.10 of this report, a survey was performed in October and November, 2018 in Casablanca and Rabat to find the approximate loss rate of fishing sinkers and lures in Morocco. The results of the survey showed that in every one kilometer of the coastline there are approximately three fishers. Out of the three fishers, only one fisher would be using soft plastic lures (SPLs), while the rest use live baits. The survey results proved that the rate of loss of October was 0.4 lure/km and 0.2 lure/km for November. Taking the average of the two, we get 0.3 lure lost per kilometer each day (See Appendices D & E).

In Morocco, for the approximate rate of loss found, and considering that the Moroccan Atlantic coastline is approximately 1835km (from Tangier to Guelmim), the quantity of lost lures in this coastline would equate to almost 550kg per year. The quantity is believed to be higher if we consider the Mediterranean, the rivers and lakes.

3.3. Effects of fishing lures on environment

3.3.1. Effects on water

As has been discussed, Soft Plastic Lures (SPLs) are made of PVC with the addition of plasticizers and of these plasticizers, more than 90% are high phthalates. High phthalates are

phthalates with 9-13 carbon atoms in their chemical backbone (American Chemistry Council). When making fishing lures, manufacturers use more than 70% of high phthalates and almost 30% of PVC. The problem with this composition is that phthalates do not chemically bind to PVC. As a result, phthalates get released easily in water. Thus, if not eaten by wildlife species, SPLs will remain in the aquatic environment as a form of pollution, and phthalates would be leached. Extensive research has been conducted to show the health effects of phthalates. It has been proven that they are hormone-disrupting chemicals and have been linked to changing sex hormone levels, low sperm count, and altered development of genitals. They have also been linked with preterm birth, worsening of asthma and allergy symptoms. Thus if the aquatic species get exposed to high concentrations of phthalates in water, this noxious substance can accumulate fishes which will be consumed by humans [35].

3.3.2. Effects on fish species and waterbirds

Soft plastic lures (SPLs) which look like natural forage provide a good substitute to cumbersome live baits. SPLs are very famous among anglers because of their durability and subsequent longevity. These features are the result of the usage of non-biodegradable synthetic polymers. Just like fishing sinkers, fishing lures get lost and discarded in aquatic systems and will not decompose even after two years of being discarded. And because of the great resemblance between artificial lures and real species, they can be ingested. Cory Suski, a researcher of University of Illinois and Steven Cooke from Carleton University in Canada conducted a study to investigate the impact of SPLs on lake trout, smallmouth and the environment. In their lab, they used eight different types of SPLs and immersed them in water at two various temperatures over a period of two years in order to evaluate their size change and their rate of decomposition. The two-year experiment has proven no decomposition over this period. Furthermore, some of the lures swelled up to 200 percent of their original volume. This can be explained by the fact that some SPLs contain porous plastics which have the tendency to swell to large sizes. The researchers believe that once the SPLs are swallowed, they will swell inside the fish and/or the waterbirds stomach until it fills all the space, which will cause digestion problems for wildlife species [5].

3.4. Characteristics of Lures

3.4.1. Size

The choice of the size and weight of the fishing lure does not stem from randomness. Water conditions are very relevant and important when choosing the size and weight. For

instance, in stronger currents and on windy days, heavy lures are usually the ideal choice. On the other hand, light fishing lures are preferable and better in calmer weather conditions.

3.4.2. Color

Lure color is an important factor the influences the fishing success. For instance, the color required in murky or muddy waters is different than crystal-clear waters. As explained by Sea Grant Institute of Wisconsin University, light behaves differently in water than in air. In fact, colors have different wavelengths, for instance red has the longest wavelength, and then followed by orange, yellow, green, blue and finally violet which has the shortest wavelength. Since light can travel through water, some of its energy will be absorbed, and the longest wavelengths will be absorbed first. It is noted that warm colors are the first to fade out and darken with increasing depth in clear waters. In other words, warm colored lures appear darker and almost black as the lure runs deeper. For instance, red lures appear black within the first 6-8 m, orange lures 11-14 m, yellow 20-23 m, while colors like green and blue can remain visible for as deep as the light penetrate. However, in turbid water, like river mouths this relationship does not hold, and is instead reversed. For instance, blue colored lures disappear first, while greens and reds remain visible in greater depths. As light is an important factor determining how lures would look like in water, it should be noted that colors of light will not penetrate as deep on a cloudy as they will on a sunny day [39].

3.4.3. Movement

Fishing lures should be made from materials that can ensure “realistic” swimming action of real small fishes, worms, minnows…etc. In order to have this realistic effect, the material should be flexible and soft. Thanks to the flexibility of the material, the movement can be vibrant, with a harmonic motion that can be horizontal but also vertical. The movement of the fishing lure is very important as it is attracts the attention of fishes and also the movement can cause water to make clicking sounds that will increase the chances of attracting a fish.

3.5. Biodegradable alternatives

Non-biodegradable polymers are taking a big part of the plastic industry and applications because of its ease of processing. Conversely, important technologies involved developing bio-polymers that can replace the man-made ones and to follow the trend of sustainability. Thanks to bio-polymers, a new kind of plastics were developed which are bio-

plastics– plastics derived from renewable abundant materials. Among these bio-plastics which can be applied in the context of fishing lures, we find:

3.5.1. Corn Starch Based Bio-plastic

Starch is a polysaccharide or a natural bio-polymer that consists of linear α-1, 4' (amylase) along with branched α-1,6' (amylopectin) structures having both crystalline and amorphous regions. Amylase and amylopectin aggregate into dense units named "granules". Depending on the starch source, the proportions of amylase and amylopectin can vary [40].

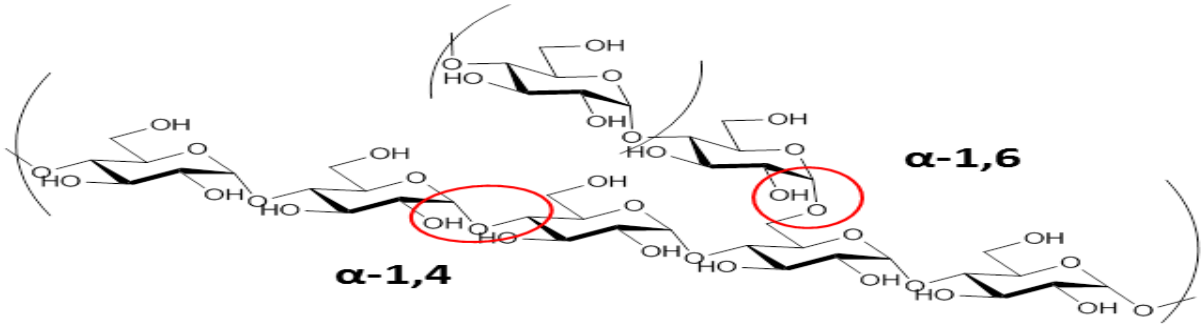


Figure 6: Molecular structure of corn starch [41]

As there were no data about attempts of making fishing lure using corn starch fishing lures, it was necessary to perform many trials in order to find the right weight of each component. During the trials, it was found that a quantity that exceeded 20g of corn starch would result in stiff lures. On the other side, a quantity of less that 20g would not fill the mold that I worked with (see Appendix F). Glycerol was a very critical component during the trials, as fishing lures that did not include glycerol turned out to get stiff and very hard after few hours of being exposed to air. Thus, to make corn starch based fishing lures in a home setting for personal use, the following process takes place:

1. Add 20 g of starch to a beaker
2. Add 15 mL of glycerin to the beaker
3. Add 50 mL of water to the beaker
4. Put the beaker on a hot plate and heat it up to 100 degree Celsius.
5. Stir the solution until it becomes thick and transparent.
6. Add glitter add/or a colorant to the mixture.
7. Pour the mixture into the mold
8. Let dry for at least 1hour before removing it from the mold

During the process explained above, heat breaks the intermolecular bonds of starch molecules. As a result, the sites where hydrogen and water bond get exposed and starch granules dissolve, this is when the starch takes the sticky gel texture. The role of glycerol or gelatin is to act as a plasticizer because it would intersperse itself between the starch polymers and by the end of the process the flexibility of the starch will increase. The glitter and colorant added can serve to catch the attention of fishes, because as already explained, fishes are attracted by colors.

3.5.2. Gelatin Based Bio-plastic

Gelatin is a bio-polymer, and is almost odorless and tasteless. It is also brittle and has a faint yellow color. In terms of components, gelatin is made of 50.5% carbon, 25.2% oxygen, 17% nitrogen and 6.8% hydrogen. Gelatin is also a denatured collagen, in other words, it is derived from collagen. Once gelatin granules get soaked in water, they hydrate into swollen particles and when they are warmed (40-50 degree Celsius) these particles dissolve and form a sticky gel. The most important properties of gelatin are its gel strength, viscosity and very low melting point almost close to the human body temperature. As the graph below illustrates, the strength of a gelatin gel increases with an increasing concentration of gelatin.

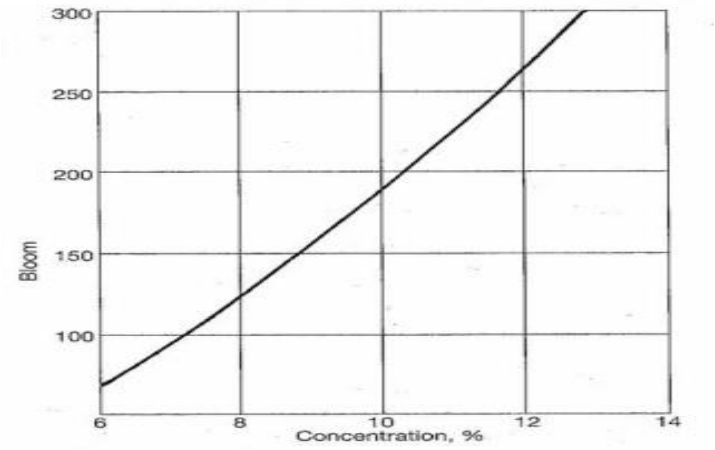


Figure 7: Gel Strength as a function of gelatin concentration at 10 C [42]

The gelatin gel which is a hydrophilic polymer has the ability of swelling (as mentioned above) and, thus can retain large amounts of water without dissolution. Gelatin gel is also soft and has low modulus of elasticity (in the order of kPa) but exhibit brittle failure and dependence with strain rate [42].

During my research I could not find data about attempts of making fishing lure using gelatin, therefore it was necessary to perform many trials in order to find the right weight of

each element. During the trials, it was found that a quantity that exceeded 15g of gelatin would result in stiff lures. On the other side, a quantity of less that 15g was not enough to fill the mold that I used (see Appendix F). Glycerol was a very critical component during the trials, as fishing lures that did not include glycerol turned out to get stiff and very hard after few hours of being exposed to air. Thus, to make gelatin based fishing lures the following process takes place:

1. Add 15 g of gelatin to a beaker
2. Add 10 mL of glycerin to the beaker
3. Add 50 mL of water to the beaker
4. Put the beaker on a hot plate and heat it up to 100 degree Celsius.
5. Stir the solution until it becomes thick and transparent.
6. Add glitter add/or a colorant to the mixture.
7. Pour the mixture into the mold
8. Let dry for at least 1hour before removing it from the mold

In a study conducted by Frontini, it was found that adding glycerol to the gelatin gel increases the water retention capacity and thus the dissolution rate. This is due to the fact that glycerol molecules are very small in size and hygroscopic (able to absorb water).

3.6. Weighted Decision Matrix

SPLs can be replaced by either a bio-plastic material (as shown above) or can be made from wood or glass. In the case of glass, there are already some glassy manufactured fishing lures, which are made from very strong and tough glass that resists breaking in case the fishing line is wrongly casted and the lure hits the rocks. As per the wood, they are available in the market, but very few anglers buy them.

3.6.1. Criteria of the Weighted Decision Matrix

A weighted decision matrix is useful in this regard because we need to compare four alternatives with respect to multiple criteria of variant levels of prioritization and importance. For instance among the most important criteria for fishing lure:

- **Strength**: the fishing lure should be strong enough not to easily snap or split. The main reason behind the heavy usage of polymers based lures is their strength, thus when selecting an alternative, this criterion should have weight of 5.
- **Flexibility**: as discussed in the movement part, movement (vertical and horizontal) is a very important factor in catching the attention of the fish. This movement can be

achieved by having a flexible material. As a result, this factor will have a weight of 5 as well.

- **Water Dissolution Rate**: one of the objectives of this project is to find an ecologically safe alternative to soft plastic lures. A safe alternative would be a lure than can degrade overtime without polluting the aquatic environment. However, the rate of dissolution or degradation should not be very high, as it should sustain for few hours. This criterion is important but with a lower priority, this is why it will have a slightly lower weight of 4.
- **Availability**: the availability of the material determines its price. Thus if there is a scarcity of the raw material, the total cost would be high. In addition, anglers in general try to find the most cost effective choice, and so the availability or cost is an important criterion and would have a weight of

3.6.2. Weighted Decision Matrix Discussion

Table 7: Weighted decision matrix for fishing lures' alternatives

Material	Strength (5)	Flexibility (5)	Water dissolution Rate (4)	Availability (5)	Total
Wood	4	1	1	4	**49**
Glass	4	1	1	5	**54**
Corn starch-based	3	4	3	5	**72**
Gelatin-based	3	5	4	5	**81**

From the weighted decision, it can be deduced that wood and glass, even though they are environmentally friendly materials, sustainable and fully recycle, they do not provide the characteristics that were discussed before (especially the flexible movement and the required sound) that can attract the attention of fishes. As per corn starch based lures, they have exhibited the nice wanted features, a flexible motion, cheap overall price and resistance to a certain tension. However, once in water, corn starch based lures dissolved in a rate higher than those made of gelatin. Anglers would prefer a lure that can sustain for the day long and this is why the rate of dissolution is important to take into account. This factor was determinant to choose gelatin based lures over corn starch lures.

3.7. Testing

As explained, the optimum alternative would be a fishing lure made of a bio-plastic that is based on gelatin and glycerol. The choice stems from the fact that after testing both corn

starch based lure and a gelatin based lure, the gelatin based lure had a better strength, higher flexibility and slightly slower water dissolution rate. Gelatin and corn starch are both naturally abundant materials that are widely available and cost effective. After testing the gelatin based lure, it could sustain for more than 24 hours until it absorbed a lot of water and the hook started detaching.

3.8. Cost Analysis

To make one lure based on gelatin and which is the optimum alternative we need, as discussed, 15g of gelatin and 15mL of glycerol. These raw materials were bought from the Moroccan market with the following prices:

- Gelatin: 35 Dhs/250g
- Glycerol: 15 Dhs/50mL

For 15g of gelatin, and 15mL of glycerol, making one fishing lure would require:

- Gelatin: 2.1 Dhs/15g
- Glycerol: 4.5 Dhs/15mL

Therefore, making one lure at home for personal use would cost approximately 7 Dhs or $.

Lures usually get lost before their maximum usage number has been reached. In that case, cheapness is an important factor in the favor of the angler. On the other hand, SPLs can be used more than once, and in that case the price of the gelatin based lure will be higher. However, the whole objective of this project was to design a lure that can dissolve, and if the fact that SPLs do not dissolve was a factor to avoid.

4. Fishing Floats

4.1. Description of fishing floats

Fishing floats or bobbers as called in the US are items of the fishing tackle. They are used mainly in the US and UK. They are usually made of materials characterized by small density and being buoyant. They have a hole through their center through which the fishing line is attached. Fishing floats are used for a couple of purposes:

- When the fishing line is casted, the float (because of its buoyancy) would suspend the bait or lure at a desired and determined depth.
- It also carries the bait/lure to a desired but inaccessible area of water, by allowing the fishing float to drift in the prevailing current.
- Floats are colored (usually in red) at their tip which visually allows the anglers to spot the location of the fishing line and so to keep a reference point to where the bait is.

The designs of fishing floats vary depending on the weather conditions, water flow, and the type of bait/lure used [43]. The main used designs of fishing floats are:

- **Bubble:** This type of floats comes in the form of small hollow balls made of plastics. The feature of being hollow allows the angler to partially fill them with water and to control the degree of the floating above water. Their round shape allows them to be used when the other shapes of floats cannot be used as they can drift into the area without tangling or snagging between rocks.
- **Dink**: This type has a cylindrical shape made of black polyurethane foam which is characterized by its very low density. It is also usually colored by red at the top as a form of visual indication.
- **Popper**: It is a type of fishing float designed to mimic a fish at the surface. Some popper floats include a metal wire with breads at the end to make a clicking noise whenever pulled in water.
- **Quill**: It is one of the oldest float types which are made originally from birds' feathers and which have a very light weight [43].

4.2. Effects of Fishing Floats on Environment

Concerns about the environmental effects of plastics in the environment and in particular their damaging effects on marine environments, animals and birds have exponentially increase the last decade. As discussed in the description part of the fishing

floats, they are most of the times made of plastics and polyurethane foam which are noxious. There are no studies done to investigate how many fishing floats are lost to the environment nor their potential effects. However, after looking at the rate of loss of both fishing lures and sinkers, it can be assumed that fishing floats get lost and discarded with a rate of loss approximate to that of fishing lures. Since fishing floats are made of polymers with the main ones polystyrene, EPS and polyurethane, it will be important to look at their present effects on marine environments in order to have a scale of the potential effects of floats.

The main problem with polystyrene, EPS is that it takes up a very high fraction of landfill space because of its lightweight. Thus when lost in water, the space it would take is expected to be high. Moreover, polystyrene is non-biodegradable, which takes thousands of years to decompose. Once the EPS foam breaks apart, the small polystyrene components can easily enter the digestive systems of animals, this can cause choking or intestinal blockage. In marine environments, EPS foam can be consumed by fishes once it breaks down. In the food chain, marine species that are at the top might eat fishes that have consumed EPS, therefore concentrating the contaminant. This is can potentially be hazardous for us humans who are on top of the food chain. Especially that US National Institutes of Health (NIH) and the International Agency for Research on Cancer (IARC) have classified styrene, a plastic monomer derived from petroleum used in manufacturing EPS as a possible human carcinogen [44].

4.3. Weighted Decision Matrix

4.3.1. Weighted Decision Matrix Criteria

In order to design a performing float that will not sink and which will suspend the bait to the desired depth the angler wish, it is necessary to take these factors into account:

- **Density**: As the name of the component suggests, it should be floating. Thus the density of the material to be chosen is critical. In order to ensure a floating behavior, it is necessary that the density of the fishing float to be lower than 1023.6 kg/m^3, which are the density of seawater at a temperature of 25 °C, salinity of 35 g/kg and pressure of 1 atm. Therefore, as density is the relevant factor that determines if the component will float or not, this criterion will have a weight of 5.
- **Hazardous emission:** The aim is to replace existent and currently manufactured fishing floats with safes ones. Therefore, the material to be chosen and which will

replace the environmentally harmful ones should not have any toxic profile and thus be ecologically safe. Since this is an important factor, it will have a weight of 5.

- **Price**: The price is an important factor that alters the purchasing decision. The material to be chosen should have a reasonable price that does not exceed the price of currently manufactured ones in order for the suggested alternative to have a position in the market. This criterion will also have a weight of 5.

4.3.2. Weighted Decision Matrix Discussion

Table 8: Weighted decision matrix for fishing floats' alternatives

Material	Density (5)	Hazardous emission (5)	Price (5)	Total
EPS	5	1	4	**50**
Polyurethane	4	2	5	**55**
Balsa wood	3	5	3	**55**
Cork wood	3	5	3	**55**

In order to design fishing floats that respond to the demands of anglers, the fishing floats should meet their main feature that is to "float". In order to determine if an object will sink or float, its buoyancy force should be determined. Buoyancy refers to the force exerted on an object that is wholly or partly immersed in a fluid. For an object to float its density should be lower than the density of the liquid in which it exists. As a result, the weight of the object will equal the buoyant force.

For the materials mentioned in the table, their density is as follow [45]:

- Polystyrene EPS: 11-32 kg/m^3
- Polyurethane: 16-62 kg/m^3
- Balsa wood: 40-340 kg/m^3
- Cork wood: 160 kg/m^3

As discussed before Polystyrene EPS and Polyurethane are both thermoplastics that cause many issues because of their lost weight. They easily break down in water and are consumed by wildlife species. As a result, they get concentrated in their tissues, and once consumed by humans who are at the top of the food chain, they can be carcinogen.

The following materials also have the following prices per unit based on Amazon:

- Polystyrene EPS: 0.6$/unit
- Polyurethane: 0.7$/unit
- Balsa wood: avg. price $1/unit
- Cork wood: avg. price $0.9/unit

From the weighted decision matrix, the total for polyurethane, balsa wood, and work were the same. In this case, balsa or cork wood can be chosen over polyurethane as they are naturally occurring materials, unlike polyurethane that hardly decompose in nature and water systems. For the Moroccan context, we would choose Balsa wood as it is widely available in Maamoura Forest.

5. Steeple Analysis

This capstone project involves many external factors that affect many aspects. The STEEPLE Analysis which is a crucial strategic planning tool will outline these factors and aspects. Since this tool is more detailed than the SWOT analysis, we will have a complete and successful analysis which will meticulously take into account all the measures and implications.

Social Implications: This project promotes being socially responsible as it suggests safe material alternatives compared to the ones currently manufactured. If recreational anglers adapt the new alternatives suggested in this project, many wildlife fishes and birds would survive a grand potion of harm caused by the human being. Anglers use the cheapest and widely available materials (i.e. lead sinkers, SPLs, plastic floats), but if the market is equipped with safe alternatives, that are widely commercialized, then the behavior and habit of the anglers will surely change and adapt to the new trend.

Technological Implications: In order to implement this project, technology is crucial. There are many materials that can replace lead in sinkers or silicon in lures, but technology can save the hassle of looking for each of them and of their characteristics. Thanks to technology, simulations can be run, and information about each material can be found. Also, thanks to technology, new materials can still come to the surface and which can even better replace the ones suggested. So for instance, this project can even be the subject of an advance and more detailed research to find a new material that can be used in fishing tackle.

Ethical Implications: Not all anglers will react to the change rapidly. However, a small change in morality is expected to happen. According to some research, many anglers are ready to adopt the lead fee sinkers, but the alternatives are just unavailable or if they happen to exist are still very expensive. Adopting the suggested alternatives will also be a big action toward protecting our oceans and wildlife.

Environmental Implications: The aim of this project is to protect our oceans and wildlife through substituting the current noxious fishing tackle by a safe one. This makes out of this capstone and its purpose environmentally driven par excellence. Wildlife suffers in silence– angling is an activity supposed to be a fun pastime for humans, but it turned out to a pain for wildlife. Only few countries shed light on this environmental issue (i.e. Canada, USA) while many others are indifferent or simply do not understand the gravity of this

problem. This is why this project will suggest solutions and suggestions to prove that there are alternatives, that things can change and that we can do something for wildlife.

Political Implications: In the US, the following states: Maine, New Hampshire, New York and Vermont have banned the use and sale of lead sinkers. Moreover, the United States Fish and Wildlife Service issued a directive to ban lead sinkers by 2022 in all of America. This legislative action has caused concern in the UK, which started questioning whether they have to ban lead or not. Canada is also currently discussing the possibility to moving toward a lead free fishing-tackle. As per the Moroccan context, just like banning plastic bags, this project can encourage the concerned authorities to implement a political action against environmentally harmful fishing tackle.

Legal Implications: Some countries have set some regulations of manufacturing and usage of fishing tackle. For instance, in the states of New York and Maine, the sinkers that weigh less than an ounce & lead jigs smaller than 1 inch are illegal. Hence, in this project along with suggesting new safe materials to replace the harmful ones, dimensions and regulations of the manufacturing will be outlined too. It is important to define the legal dimensions and size in order to avoid the consumption of these materials by water birds, and fishes.

Economical Implications: Some suggested materials can have a slightly higher price than the ones being used in manufacturing (e.g. lead sinkers). However, if the consumers switch to these new alternatives, the economies of scale will kick in. With a higher demand for the newly suggested alternatives, their price will decrease and thus they will become affordable by all anglers. The trend among companies nowadays is being environmentally friendly and sustainable, so companies can follow this sustainable trend and change to safe raw materials with which they can manufacture safe fishing tackle. Additionally, if many anglers demand environmentally friendly fishing tackle, this can be a business opportunity to be seized by entrepreneurs and investors and which can contribute to the economy.

6. Limitations & Future Work

Throughout this project there were many challenges and limitations. First, recreational fishing is not an activity that is well documented in countries other than a handful of European countries and North America. I first had many challenges in the literature review as little research has been done in this field. This project included papers that described the currently used materials in the fishing tackle but not offering solutions or suggesting alternatives. This task was left to manufacturers who labeled even toxic alternatives as "environmentally friendly" substitutes. As per the fishing floats, there has been absolutely no research to even investigate the potential harms of the materials which constitute them. This lack of available data obliged me to limit my scope of analysis.

Furthermore, many assumptions throughout this study had to be made in order to carry on with the research. For instance, I could not find a research or a study journal that describes the process of sol-gel for metals other than stainless steel. Other assumptions had to be made in order to have an idea about the problem' scale globally, as only a handful countries had statistics of their anglers.

In Morocco, there was no data or statistics about the recreational fishing activity. It was necessary for the sake of this project to get a picture of the problem's scale and this is why I had to do a sampling study. As there were no statistics about the number of anglers in Morocco, I had to go to Casablanca and Rabat in order to interview anglers on-site and gather data that can be extrapolated over the Atlantic coastline. The rates and quantities of fishing lures and sinkers are subject to small variations as the studied area was not large enough to increase the confidence interval.

The future work of this project would evolve around testing the suggested alternatives in a sea setting. This includes testing the gelatin based fishing lures attached to a fishing line with a hook and verifying its performance in seawater and freshwater settings. It would include performing the sol gel method on lead sinkers and verifying if the number of TiO_2 layers is good enough in the long term.

7. Conclusion

The increasing interest in environmental issues and the increasing demands to replace harmful materials and develop materials that do not burden the natural environment significantly are currently observed. In this connection, this capstone project tackled an environmental topic that started gaining attention recently because of the toxicity of the materials it involves. Recreational fishing is considered as a sport or a leisure activity that should be a pleasant pastime for those who are fan of it. However, it has been proved that this pleasant pastime costs a lot and comes with high detrimental effects. Because fishing sinkers, lures and floats get lost in the environment at big quantities that accumulate over years.

First, lead fishing sinkers were found to be toxic to our aquatic systems as they get dissolved in acidic water. They also get ingested by waterbirds that confuse them with small stones or grit used in facilitating digestion. Once ingested, lead reacts with stomach's acid which is lethal. In order to overcome this environmental crisis, we suggest coating lead sinkers with TiO_2 using sol-gel method in order to ensure a pure and homogenous coating throughout the surface. We believe that three layers of this thin film will provide the sinkers with enough resistance to harsh environment (such as inside waterbirds' stomach).

Second, soft plastic lures (SPLs) were found to be dangerous as well as they contain plasticizers such as phthalates which exhibit a very toxic profile. Lures, just like sinkers, get lost and discarded, and their presence in aquatic environments is a real threat to water and wildlife species. It was found that species such as waterbids would eat SPLs after confusing them with real small fishes. SPLs tend to swell inside the digestive track and fill in all the space which causes serious digestive problems. In order to overcome this threat to the environment, we suggest using bio-plastics and making lures at home. The process is easy and provides good biodegrade substitute as it consists of only two main ingredients: gelatin and glycerol.

Finally, for the fishing floats, we considered that they get lost with an approximate rate loss of fishing lures. They were found to be manufactured using thermoplastic polymers and which can create various environmental issues. As a result, in this study we suggest making floats out of work which is a cost effective option. If recreational fishers adapt these alternatives, we believe that an unnoticeable problem can be solved and therefore, this activity can be ecologically safe.

8. Bibliography

[1] V. Thomas, "Attitudes and Issues Preventing Bans on Toxic Lead Shot and Sinkers in North America and Europe", *Environmental Values*, vol. 6, no. 2, pp. 185-199, 1997.

[2] Scheuermann et al., "Lead fishing sinkers and jigs in Canada; Review of their use patterns and toxic impacts on wildlife", 2003. Retrieved from https://www.researchgate.net/publication/287181064_Lead_fishing_sinkers_and_jigs_in_Canada_Review_of_their_use_patterns_and_toxic_impacts_on_wildlife

[3] Rattner et al., "Sources and Implications of Lead Ammunition and Fishing Tackle on Natural Resources", 2008. http://wildlife.org/wp-content/uploads/2014/05/Lead08-1.pdf

[4] Jacks et al., "Lead emissions from lost fishing sinkers", 2001. https://www.academia.edu/29385780/Lead_emissions_from_lost_fishing_sinkers?auto=download

[5] Suski, C. "New research suggests safer ways to use soft plastic lures", 2014. Retrieved from https://nres.illinois.edu/news/new-research-suggests-safer-ways-use-soft-plastic-lures

[6] Hester, J. "Some Considerations of the Problems Associated with the Use of Live Bait for Catching Tunas in the Tropical Pacific Ocean". Retrieved from https://spo.nmfs.noaa.gov/sites/default/files/pdf-content/MFR/mfr365/mfr3651.pdf

[7] Fishing Tackle. Fishing Sinkers – Types, Sizes & Uses. Retrieved from https://badangling.com/tackle-advice/fishing-weights-types-sizes-uses/

[8F] Grade et al., "Population-Level Effects of Lead Fishing Tackle on Common Loons", 2017. https://wildlife.onlinelibrary.wiley.com/doi/full/10.1002/jwmg.21348

[9] Elmore et al., 2009. Impacts of Lead Ammunition and Sinkers on Wildlife. http://pods.dasnr.okstate.edu/docushare/dsweb/Get/Rendition-12064/unknown

[10] Minister of Environment and Climate Change. "Study to gather use pattern information on lead sinkers and jigs and their non lead alternatives in Canada", 2018. http://publications.gc.ca/collections/collection_2018/eccc/En14-308-2018-eng.pdf

[11] Hyder et al., "Recreational sea fishing in Europe in a global context", 2017. https://onlinelibrary.wiley.com/doi/full/10.1111/faf.12251

[12] Ditton R.B.. "An international perspective on recreational fishing", 2008. pp. 5–55. Retrieved from https://onlinelibrary.wiley.com/doi/10.1002/9780470697597.ch2

[13] Sporrong et al. "RECREATIONAL FISHING IN THE BALTIC SEA REGION", 2017. https://ccb.se/wp-content/uploads/2018/02/ccb_recreational_fishing.pdf

[14] Herfaut et al., "The nationwide assessment of marine recreational fishing: A French example", 2013. https://archimer.ifremer.fr/doc/00144/25498/24101.pdf

[15] Hammen, T et al., "Estimating catches of marine and freshwater recreational fisheries in the Netherlands using an online panel survey", ICES Journal of Marine Science, Volume 73, Issue 2, 1 February 2016, Pages 441–450, Retrieved from https://doi.org/10.1093/icesjms/fsv190

[16] Statista. The statistical Portal. https://www.statista.com/topics/1163/recreational-fishing/

[17] "RECREATIONAL FISHERS IN AUSTRALIA: A social Snapshot", *Ozfish*. 2017. [Online]. https://ozfish.org.au/wp-content/uploads/2017/05/Recreational-Fishers-in-Australia-a-social-snapshot-sml.pdf

[18] "Chemicals Description", *RSC*. [Online]. Retrieved from http://www.rsc.org/periodic-table/element

[19] "Tungsten (Wolfram): Properties, Production, Applications & Alloys", *The Balance*. [Online]. https://www.thebalance.com/metal-profile-tungsten-2340159

[20] "Prices of metals and commodities". *Business Insider*. [Online] https://markets.businessinsider.com/commodities

[21] Haley & Kurnas. "Toxicity and Fate Comparison between Several Brass and Titanium Dioxide Powders", 1998. Retrieved from http://www.dtic.mil/dtic/tr/fulltext/u2/a270185.pdf

[22] "Corrosion profile of Brass", *CorrosionPedia*. [Online]. https://www.corrosionpedia.com/definition/6644/brass-corrosion

[23] "Profile of Copper". [Online]. http://www.imc-ma.com/data_sheet_pdfs/IMC_Safety%20Data_Copper.pdf

[24] The Editors of Encyclopaedia Britannica, 2018. [Online]. https://www.britannica.com/science/copper

[25] Besser & Leib. “Toxicity of Metals in Water and Sediment to Aquatic Biota”, 2007. Retrieved from https://pubs.usgs.gov/pp/1651/downloads/Vol2_combinedChapters/vol2_chapE19.pdf

[26] Profile of Zinc. http://www.imc-ma.com/data_sheet_pdfs/IMC_Safety%20Data_Zinc.pdf

[27] Lewis, R.J. Sr.; Hawley's Condensed Chemical Dictionary 14th Edition. John Wiley & Sons, Inc. New York, NY 2001., p. 1190. Retrieved from http://www.totalmateria.com/Article40.htm

[28] Bismuth Profile. [Online]. https://www.thebalance.com/metal-profile-bismuth-2340128

[29] Kearns & Turner. 2015. An evaluation of the toxicity and bioaccumulation of bismuth in the coastal environment using three species of macroalga. https://www.researchgate.net/publication/283687403_An_evaluation_of_the_toxicity_and_bioaccumulation_of_bismuth_in_the_coastal_environment_using_three_species_of_macroalga

[30] Profile of Nickel. [Online]. http://www.imcma.com/data_sheet_pdfs/IMC_Safety%20Data_Nickel.pdf

[31] Titanium Dioxide Profile. [Online]. https://pubchem.ncbi.nlm.nih.gov/compound/titanium_dioxide

[32] Curkovic et al., Enhancement of corrosion protection of AISI 304 stainless steel by nanostructured sol–gel TiO2 films, 2013. http://repozitorij.fsb.hr/4012/1/Enhancement_Curkovic.pdf?fbclid=IwAR0qH6m0w3x6SWodkle6hSnpDxCZ4pjTeoPZ8ujc0emtgokSHl6aX1EkoY0

[33] “Fishing Lures”, *Sierra Trading Post*. [Online]. Retrieved from: https://www.sierratradingpost.com/lp2/fishing-bait-and-lures-guide/

[34] Niedermier, C. “A Bass Angler’s Tackle Box: Buzzbaits”, 2017. https://fishing.boyslife.org/bass-anglers-tackle-box-buzzbaits/

[35] PVC Description. [Online]. https://www.chemicalsafetyfacts.org/polyvinyl-chloride/

[36] Godwin, A. Plasticizers, 2017. https://www.sciencedirect.com/topics/materials-science/plasticizers

[37] “Phthalates”, *American Chemistry Council*. [Online]. .https://phthalates.americanchemistry.com/

[38] Raison et al. “Exploring the Potential Effects of Lost or Discarded Soft Plastic Fishing Lures on Fish and the Environment”. http://www.fecpl.ca/wp-content/uploads/2014/01/Raison-et-al-2014_Water-A-S-Poll.pdf

[39] “Selecting Lure Colors for Successful Fishing”. *WISC*. [Online]. http://www.seagrant.wisc.edu/Home/Topics/FishandFisheries/Details.aspx?PostID=1702

[40] Lu et al. “Starch-based completely biodegradable polymer materials”, 2009. Retrieved from http://www.expresspolymlett.com/letolt.php?file=EPL-0000946&mi=d

[41] “Figure of corn starch”. [Online]. https://www.megazyme.com/images/default-source/product-profile/starch.png?sfvrsn=309679ad_2

[42] Frontini et al., “Mechanical and Fracture Behavior of Gelatin Gels”, 2013. https://www.gruppofrattura.it/ocs/index.php/ICF/icf13/paper/viewFile/11503/10882

[43] “Fishing Floats”, *Wikipedia*. [Online]. https://en.wikipedia.org/wiki/Fishing_float

[44] “Dealing with Polystyrene Wastes”, *Ecomena*. [Online] https://www.ecomena.org/polystyrene-wastes/

[45] “Densities of common materials”, *Engineering Box*. [Online] https://www.engineeringtoolbox.com/density-materials-d_1652.html

Appendix A – Survey of rate of loss of fishing tackle

Rate of loss of fishing sinkers and lures in Morocco

Fishing sinkers
1. How many fishing sinkers do you loose per fishing day:
2. How many days do you go fishing per year:
3. Do prefer fishing in the sea or lakes:
4. How do your fishing sinkers get lost:

Fishing lures
5. Do you use SPLs or live baits:
6. How many fishing lures do you loose per fishing day:
7. How do your fishing lures get lost:

Appendix B – Survey results of October for fishing sinkers

Studied Area (1km per studied area)	#of sinkers lost/ avg. fishing day/3 anglers
1	3
2	2
3	1
4	5
5	4
6	4
7	5
8	3
9	2
10	2
11	2
12	1
13	1
14	2
15	3
16	3
17	4
18	4
19	5
20	3

Appendix C – Survey results of October for fishing sinkers

Studied Area (1km per studied area)	#of lost sinker/ fishing day/angler
1	2
2	2
3	3
4	4
5	5
6	4
7	3
8	2
9	3
10	4
11	5
12	4
13	3
14	5
15	3
16	2
17	1
18	2
19	5
20	1

Appendix D – Survey results of October for fishing lures

	Number of anglers using SPLs	Number of SPLs lost/angler/day
1	2	1
2	0	-
3	1	0
4	1	0
5	0	-
6	1	1
7	1	0
8	2	1
9	1	0
10	1	1
11	1	1
12	0	-
13	1	0
14	2	1
15	1	0
16	0	-
17	1	1
18	1	0
19	0	-
20	2	0

Appendix E – Survey results of November for fishing lures

	Number of anglers using SPLs	Number of SPLs lost/angler/day
1	0	-
2	1	1
3	1	0
4	1	0
5	0	-
6	1	1
7	1	0
8	1	0
9	0	-
10	0	-
11	1	1
12	0	-
13	1	0
14	1	0
15	0	0
16	0	-
17	1	1
18	1	0
19	0	-
20	1	0

Appendix F – Steps of making gelatin-based lures



Step 1: Addition of the required ingredients in a baker



Step 2: Addition of water and heating up the mixture.



Step 3: Make a mold using gypsum



Step 4: Pour the mixture in the mold

